

# Thermal Performance Evaluation of Daniellia Oliveri, Erythrophleum Suaveolens and Piliostigma Thonningii Charcoal Briquettes for Sustainable Energy in Bauchi State, Nigeria

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**Abstract-** This study investigates the thermal performance of charcoal briquettes produced from three different biomass sources: *Daniellia oliveri* (Aduwa), *Erythrophleum suaveolens* (Marke), and *Piliostigma thonningii* (Kalgo) with the aim of evaluating their suitability as sustainable alternatives to fossil fuels. The briquettes were produced using a standardized carbonization process. Key performance metrics such as calorific value, burning time, ignition time, and thermal efficiency were evaluated. Results show that Marke briquettes exhibited the highest calorific value (18.5 MJ/kg), followed by Kalgo charcoal (15.8 MJ/kg) and Aduwa charcoal (15.3 MJ/kg). Oxygen index

(*Piliostigma thonningii*), and Marke (*Prosopis africana*). These species are known for their hardness,

availability, high density and slow-burning properties, making them suitable for charcoal production (Njenga et al., 2016). The objective of this research is to evaluate the thermal performance of the charcoals briquettes from these species in terms of calorific value, burning rate, ignition time, and ash content etc.

The use of wood stove is one of the most basic human needs that must be met in adequate quantity to sustain life with minimum health hazard. The 3 - stone fires are the most commonly used means of cooking in most households in Nigeria and Africa at large (Garba et al, 1997). Considerable amount of heat is wasted in its use and the smoke generated from burning wood has been found to be harmful to its users. The present practice of using 3 – stone type wood stove is time consuming and possess a lot of health hazards. The wood burning stoves have been commonly used to arrest the effect of smoke generated on the user and reduce its high fuel consumption and also means of improving the efficiency in utilization of the fuel (Lawal et al, 2022)

## I. INTRODUCTION

The global demand for energy continues to rise amid growing concerns over fossil fuel depletion and climate change. In developing countries, traditional biomass remains a primary source of domestic energy, especially in rural and peri-urban communities. However, in efficiencies and environmental concerns related to raw wood burning necessitate the development of alternative fuels such as biomass briquettes. In many developing regions, wood charcoal remains a primary energy source for cooking and heating, contributing to deforestation and environmental degradation. Briquettes made from agricultural and forestry residues offer a sustainable alternative, reducing waste and improving energy efficiency (Kpalo et al., 2020).

This study focuses on three indigenous West African wood species: Aduwa (*Balanites aegyptiaca*), Kalgo

### 1.1 Brief Description of the Wood Species

1. Daniellia Oliveri: - The English Common name of Aduwa tree is Copaiba Balsam tree (less common), while its scientific name is *Daniellia oliveri* tree. It is widely distributed in West Africa, especially in Nigeria, and known for its use as firewood, gum production, timber, and medicinal purposes. The

Calorific Value of Aduwa wood is estimated to 16–18 MJ/kg. It is a medium-density hardwood, good for firewood and charcoal. Burns steadily but not as long-lasting as denser woods.

2. *Erythrophleum suaveolens*: - is native to tropical Africa and is widely known for its hard, heavy, and durable tree. The English Common Name of Marke tree is Ordeal Tree, while *Erythrophleum suaveolens* is the scientific name. It has a very dense and hard wood, Resistant to termites and decay, and the back of the tree contains toxic alkaloids. The Calorific Value Marke wood : - As a hardwood, its calorific value is relatively high. Estimated calorific value: 17–20 MJ/kg (megajoules per kilogram). This makes it a good firewood but sometimes avoided due to its toxic smoke if not properly seasoned.

3. *Piliostigma thonningii* : - commonly known as camel's foot, monkey bread, or mortar tree, is a widely found tree in savanna regions of Africa and is known in Hausa as Kalgo. The Calorific Value of *Piliostigma thonningii* Wood is Estimated to be 16–18 MJ/kg (megajoules per kilogram). This range is typical for medium-density hardwoods. The value depends on factors like moisture content, age of the tree, and drying method.

### 1.2 Charcoal Briquette

A charcoal briquette is a compact block made from charcoal dust, biomass, or coal fines, bound together with a binder and compressed into a solid form. It is commonly used as cooking fuel and for industrial heating because it burns longer and more evenly than regular firewood or loose charcoal. The Advantages of Charcoal Briquettes are its burns longer than lump charcoal, consistent heat and size, utilizes waste biomass, and low smoke when properly prepared. Charcoal briquettes, especially from agricultural and forest residues, are gaining traction as clean and renewable energy carriers.

### 1.3 Aim and Objectives

1.3.1 Aim: - The aim of this study is to assesses the thermal performance of charcoal briquettes produced from three locally available Nigerian wood species (*Daniellia Oliveri*, (Aduwa), *Erythrophleum*

*suaveolens* (Marke), and *Piliostigma thonningii* (Kalgo).

1.3.2 The objectives are:

1. To evaluate their viability as sustainable fuels in terms
2. To evaluate the combustion efficiency and
3. The heat output.

## II. MATERIALS AND METHODS

### 2.1 Sample Collection and Preparation

Wood logs of (*Erythrophleum suaveolens* (Marke), *Piliostigma thonningii* (Kalgo), and *Daniellia Oliveri* (Aduwa). were sourced from Badaromo village in Ganjuwa local Government, Bauchi State, Nigeria.

2.1 Carbonization: - The logs were air-dried for two weeks and then carbonized using a kiln at 450°C for 6 hours (ASTM D1762-84). That is burning the organic material (wood) in a low-oxygen environment to convert it into charcoal. The resulting charcoals were pulverized and sieved through a 2 mm mesh.

### 2.2 Briquette Production

A 5% starch solution (cassava-based) was used as a binder. The charcoal powder and binder were thoroughly mixed in a 4:1 ratio by weight and compacted using a manual hydraulic press. The cylindrical briquettes (diameter: 4 cm, height: 3 cm) were dried under the sun for 5 days.

### 2.3 Configuration of burning stove

The stove setup size of 500mm x 300mm x 250mm and has a wall thickness of 30mm with no grate and used as the experimental test rigs.

### 2.4 Characterization of Thermal properties

1. Limiting oxygen index (LOI): ASTM D2863 methods was adopted and the relationship of the limiting oxygen index and the mixture of oxygen and nitrogen are given as

$$LOI(\%) = \frac{O_2}{O_2 + N_2} \times 100 \quad (2.1)$$

Where; O<sub>2</sub> = Volumetric flow of oxygen (cm<sup>3</sup>/min),

$N_2$  = Volumetric flow of nitrogen (cm<sup>3</sup>/min).

2. Calorific value: The calorific value or heat liberated is determined by using fuel/food calorimeter model LO 4-340, manufactured by Griffin and George Limited, England.

3. Performance evaluation of charcoal burning rates

The water boiling test (WBT) was adopted. Pieces of charcoal briquettes samples were weighed in a weighing balance before being used to boil one liter of water in stove. The fire is extinguished when the water boils completely. To determine the weight of charcoal briquettes consumption required to boil one liter of water, the remaining briquettes pieces is collected and weighed, and the time taken for the water to boil was also observed with a stopwatch and recorded.

4. Determination of charcoal briquettes combustion temperature.

The charcoal briquettes species were used as fuels for the sample stoves. The flame temperature of the fuel briquettes under study was measured with the aid of a German made HBC, Geroz Watt Metre, model 4014 connected to thermocouple. The thermocouple's probe was positioned at four different equidistant points, and the readings of the combustion temperature were taken after every minute for an experimental duration of twenty minutes.

### III. RESULTS AND DISCUSSION

#### 3.1 Results of Calorific Value and Oxygen Index Analyses Performance Tests

1. From table 1, Calorific Value test were conducted results showed that Erythrophleum suaveolens (Marke) charcoal briquettes had the highest calorific value (18.5 MJ/kg), followed by Piliostigma thonningii (Kalgo) charcoal (15.8 MJ/kg) and Daniellia Oliveri (Aduwa) charcoal (15.3 MJ/kg). Erythrophleum suaveolens (Marke) charcoal also exhibited the lowest ash content (5.0%)

and longest burning duration (110 minutes), making it the most efficient. These findings suggest that Erythrophleum suaveolens (Marke) charcoal is the most suitable for high-performance briquette production, offering a sustainable alternative to traditional fuels, the highest flame temperature of 460 °C is Erythrophleum suaveolens charcoal, while Daniellia Oliveri is 430 °C and Piliostigma thonningii exhibited 320 °C.

Table 1: Properties of charcoal Species

Parameter	Aduwa	Kalgo	Marke
Calorific value (MJ/kg)	15.3	15.8	18.5
Flame temperature (°C)	430.0	320.0	480.0
Oxygen index (%)	24.5	33.5	24.0
Ignition Time (sec)	45	40	30
Thermal Efficiency (%)	29.4	32.1	34.8
Ash contain (%)	6.0	5.7	5.0
Carbon contain (%)	70.4	70.0	73.0

2. As for the Oxygen index analyses : It could be also, seen in table 1, that Kalgo exhibited the highest value of 33.5% of oxygen index while, others exhibited lower values. The implication of the outcome of these results is that, the higher the calorific value of a charcoal, the higher the likely hood to generate higher flame temperature, and the lower oxygen index is required to support the combustion. All briquettes displayed low moisture and ash content, indicating good combustion characteristics. marke showed the highest fixed carbon, suggesting longer burning duration and higher energy content.

3. Thermal Efficiency: Table 1, revealed that marke has the highest of 34.8 %. The thermal efficiency indicating that Marke charcoal convert more of their stored energy into usable heat. Also exhibited the lowest ash content (5.0 %) and highest carbon contain (73 %), indicating better combustion efficiency. Marke again outperformed others, attributed to its lowest ash content and higher carbon contain and energy density. But all the three charcoal types falls within the ranged to produced minimal smoke, making them

suitable for indoor use with improved cookstoves.

### 3.2 Results of Burning Characteristics and Thermal Efficiency Performance Tests

1. Ignition and Burning Time : Marke charcoal briquette sample ignited relatively quickly within 30 seconds in table 1, showing the shortest time and had the longest burning time, making it more efficient for cooking applications. The rate of burning (rate of heat released) is determined by the manner in which the air required for combustion gets supplied to the burning charcoal.
2. Therefore, proportional relationship exists between charcoal briquettes consumption (burning rates) and air supply seems relevant in the present context.

Table 2: Effect of charcoal burning rate at a mean air velocity of 33.9 m/s

Types of fuel wood	Fuel charcoal burning rate (g/min)			Mean rate	Duration (min)
Aduwa	10.94	21.95	21.69	18.20	90
Kalgo	12.00	17.05	16.94	15.33	100
Marke	15.51	15.13	15.09	15.24	110

Table 2, shows the result analysis which revealed that aduwa (18.20g/min) exhibited the highest charcoal consumption rate, followed by kalgo and marke having the least fuel consumption rate of 15.33 g/min 15.24 g/min respectively. Marke charcoal had the slowest burning rate (15.24 g/min) and longest burning duration (110 min), making it more efficient for prolonged heating applications.

Table 3: Mean Temperature of Different Charcoal Burning

Types of charcoal	Burning duration (mins)	Combustion temperature (°C)				
		T1	T2	T3	T4	Mean
Aduwa	5	28.6	35.3	38.4	40	35.58
	10	68.	77.	89.2	98.7	83.53

		4	8			
	15	76.3	82.2	90	105.6	88.53
	20	78.4	90.1	99.3	101.3	92.28
Kalgo	5	17.8	18.5	23	24.2	20.88
	10	39.5	45.6	77.5	80.3	60.73
	15	60.7	65.1	79.4	89	73.55
	20	75.8	79.9	94.1	98.4	87.05
Marke	5	19.8	20.6	24.8	26	22.80
	10	44.4	52	55.1	65.4	54.23
	15	70.1	83.4	86.2	93.2	83.23
	20	99.2	94.6	111.1		

### 3. Charcoal Briquettes Burning Rate

Table 3 also shows the mean combustion temperature of charcoal briquettes at different burning duration. where Marke charcoal exhibited the highest mean combustion temperature of 105.0 oC at maximum burning duration of 20 minutes. While, Kalgo charcoal having the least mean combustion temperature of 20.88 0C at 5 minutes. This indicates that the combustion temperature increases with charcoal briquettes burning duration.

## IV. CONCLUSIONS

The growing gap between availability and demand for firewood, coupled with the scarcity and increasing price of fossil fuels, the poor thermal performance and pollution caused as a result of burning inappropriate wood species. This study demonstrated that all three biomass species; (Aduwa, Marke, and Kalgo) charcoal briquettes and among them, Marke charcoal briquettes showed superior thermal performance in all measured parameters, making it a strong, efficient and suitable for domestic energy applications. While, the Kalgo and Aduwa charcoal briquettes also performed satisfactorily and may serve as sustainable alternatives in local energy systems.

## V. RECOMMENDATIONS

1. The study recommends further scale-up and pilot testing of these briquettes in rural households and small-scale industries as viable alternatives to kerosene and firewood.
2. Promoting their adoption can reduce deforestation, improve air quality, and enhance energy sustainability in Nigeria.
3. Further research on emission characteristics of each charcoal briquette type.
4. Exploration of blending these biomass types for optimized performance

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