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Exploring the Formulation and Characterization of Briquettes consisting of Groundnut Shell Bio-coal as a Primary Component

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Abstract: *In this study, we investigate the preparation and characterization of groundnut shell bio-coal blended briquettes as a sustainable and renewable energy source. Blends of groundnut shell and coal were formulated in various ratios (100:0, 90:10, 85:15, 80:20, 75:25, and 70:30) with starch and calcium hydroxide as binders. The results showed that the ash composition of the coal was higher than that of the groundnut shell and that toxic pollutants such as As and Pb were more prevalent in coal than in the groundnut shell. Additionally, the sulphur content of coal was much higher than that of groundnut shell, indicating a higher tendency for the coal to emit sulphur (IV) oxide during combustion. However, the groundnut shells were found to have a higher cellulose and lignin content, making them a suitable biofuel source. Coal's high carbon content makes it a valuable fuel for electricity generation. The groundnut shell-coal blended briquettes had a lower moisture content (ranging from 10-30%) and ash content (ranging from 10-30%) than the control. As the biomass content in the briquettes increases, the density of the samples also increases, making transportation easier. The ignition time of the briquettes decreases with an increase in biomass content, and the compressive strength of the briquettes decreases due to less packed coal particles. The time taken to evaporate water decreases as the biomass content increases. This study presents that using groundnut shell biomass in coal briquettes is a promising alternative energy source, as it reduces the environmental impact of traditional coal usage while providing a cleaner and more sustainable fuel option.*

Keywords: Groundnut shell, bio-coal, briquettes, biomass and proximate analysis.

1.0 INTRODUCTION

The demand for alternative fuel sources is increasing globally as countries seek to reduce their reliance on fossil fuels and address environmental concerns such as climate change since the burning of fossil fuels, such as coal and oil, is a major contributor to climate change due to the release of carbon dioxide and other greenhouse gases into the atmosphere [1, 2].

Nigeria's biomass resources include wood, fodder, grasses, bushes, animal waste, waste from forestry, agriculture, municipal, and industrial operations, as well as aquatic biomass [3].

Biomass energy resources base in Nigeria is estimated to be about 144 million tonnes per year with about 71.9 million hectares of land considered to be arable and grasses of different kinds are among the major agricultural purposes [4]. The potential for the use of biomass as an energy source in Nigeria is very high, with 80% of Nigerians who are rural or semi-urban dwellers depending solely on biomass for their energy source [5].

Nigerians rely heavily on the use of fossil fuels for energy generation and household cooking, which has led to environmental issues such as air pollution and greenhouse gas emissions. To address these issues, there is a need to explore alternative, renewable energy sources such as biofuels, which are derived from organic materials [6].

Biomass may be used directly as an energy source for heating or converted to a cleaner fuel source, such as charcoal [7]. Other energy sources that are gotten from biomass include biogas, biodiesel, and bioethanol [7]. All these energy sources have been shown to have better combustion performance and are more environmentally friendly than direct combustion of biomass [7].

Biomass is the organic matter in trees, crops, living organisms, humans, plant materials, and organic compounds used to produce heat or generate electricity [8]. Alternative fuels, such as bio-coal blended briquettes, produce fewer emissions when burned, making them a cleaner and more sustainable energy source [9].

Groundnut shell bio-coal blended briquettes are an attractive alternative fuel option due to their environmental and economic benefits, such as easy storage, transport, a longer burning period, and the fact that they burn more efficiently than either groundnut shells or bio-coal alone [10].

This makes them a convenient and reliable fuel source for a variety of applications, as several types of research on bio-coal briquettes have been carried out using some of these biomass resources.

Previous similar works by various authors have given different insights and directions to the formulations of groundnut Shell-based bio-coal briquettes.

Suman, S. (2020) conducted an experiment to create fuel briquettes from cassava rhizome waste and various binders, including molasses, starch gel, concentrated slop, cassava pulp, and soybean residue. He discovered that, the physical properties of the briquettes improved as the number of binders increased, and that briquettes made with molasses, starch gel, and concentrated slop in a ratio of 6:4 or 7:3 had the highest density, compressive strength, impact resistance, and calorific values. An economic analysis showed that these briquettes also had the highest benefit-cost ratio. [11].

Biomass densification is often necessary to improve the handling characteristics of low-density materials. To improve the quality of densified products, binders are added to comminuted biomass. Some materials naturally contain binders, but they may not be sufficient or available in a form that can contribute to binding.

Oyelaran *et al* (2015) prepared briquettes from groundnut shells and cassava starch with different percentages (5%, 10%, 15%, and 20%) of binder by weight. After sun drying the briquettes for 21 days, they were subjected to a water boiling test to evaluate their quality and suitability as a domestic fuel. The groundnut shell briquettes burned with a good flame and had a thermal efficiency of 14.47% to 18.46%, compared to 10.31% for wood. The briquettes had an average burning rate of 0.587 to 0.881 kg/hr and specific fuel consumption of 0.067 to 0.267 J/g, while wood had a burning rate of 1.166 kg/hr and specific fuel consumption of 0.332 J/g. The boiling time for the briquettes was 14.80 to 23.15 minutes for a cold start and 13.05 to 19.08 minutes for a hot start, while wood took 28.05 and 19.20 minutes for a cold and hot start, respectively. Overall, the briquettes with 20% binder performed the best [12].

Mursito *et al*, 2020, experimented with the production of bio-coal briquettes from a blend of two types of low-quality coal and biomass waste, without coal carbonization. They added a bio-activator solution to the blend and fermented it before pressurizing it into briquettes. The coal samples used had different calorific values and sulfur contents. The biomass used was fermented cow dung and had a calorific value of 4192 kcal/kg and a total sulfur content of 1.56%. The goal of the study was to determine the total decrease in the sulfur content of the blend after fermenting it with a bio-activator solution. The bio-activator solution used was made from Garant and molasses, and it decreased the sulfur content in the blend by 38% to 58%. The resulting bio-coal briquettes had a total sulfur content of 1.00% to 1.14%, which met the necessary quality requirements for non-carbonized bio-coal briquettes. The raw coal used had a dominant pyritic and sulfate content, and the organic sulfur content in the fermented bio-coal briquettes was found to be lower [13].

Shao, L. *et al. (2016)* investigate the toxicological mechanisms of the particulate matter (PM) released by coal and other solid fuel combustion. It analyzed PM10 particles that were generated during laboratory stove combustion of raw powdered coal, clay-mixed honeycomb briquettes, and wood charcoal in terms of morphology, trace element compositions, and toxicity using various methods like FESEM, ICP-MS, PSA, etc. Results indicated that the equivalent mass concentration of PM10 emitted by burning raw powdered coal was higher than that derived by burning honeycomb coal. Also, PSA results showed that PM10 emitted by burning honeycomb briquettes had a higher oxidative capacity than that from burning raw powdered coal and wood charcoal. The study found that the water-soluble elements in coal-burning-derived PM10 samples had a positive correlation with the level of DNA damage, and thus exposure risk was higher when burning raw powdered coal. [14].

Akpenpuun, T.D., *et al.* 2020 explore the use of agro-wastes like groundnut shells, rice husks, sawdust, and waste paper for the production of briquettes. The study used different ratios of the agro-wastes to make briquettes and the feedstock of each blend was pressed into square moulds using a screw press at 20 MPa for 60 seconds. The study analyzed the moisture content, density, and combustion characteristics like ignition time, and calorific value of the briquettes. The study found that the moisture content of all the briquettes was between 8-15%, the density was between 800-900 kg/m3, and the calorific value was between 0.03-0.19 and 0.02-0.27 MJ/kg. The study found that the best ratio of the agro-wastes for density and ignition time was 20% sawdust, 70% rice husk, and 10% paper. Finally, concluded that the production of briquettes from agro-wastes is an effective and efficient agricultural waste disposal technique. [15].

Generally, it has been shown that many grades of coal can be used for bio-coal production, even low-grade coal containing high sulphur contents [16, 17]. This implies that, with this technology, the extra cost of carbonizing low-grade coal before briquetting is saved. Groundnut shells are a prevalent agricultural waste product that is widely distributed in Nigeria, and they have been identified as a promising raw material for the production of biofuels. This study aims to investigate the utilization of groundnut shells as feedstock to produce bio-coal. The bio-coal was produced through the process of carbonization and subsequently blended with a binder to form briquettes. The physical and fuel properties of the prepared briquettes were evaluated, and their feasibility as an alternative fuel source in Nigeria was established.

2.0 EXPERIMENTAL

In the preparation of groundnut shell bio-coal briquettes, the first step is to collect and clean the groundnut shells to remove any impurities or contaminants. The shells are then ground into a fine powder using a hammer mill or similar equipment. The ground shells are mixed with a binder, such as molasses or starch, to hold the briquette together and improve its strength. The mixture is then pressed into briquette molds using a hydraulic press or manual press.

The briquettes were dried in the sun or in a mechanical dryer to remove any remaining moisture. The briquettes were characterized using various methods to determine their physical, chemical, and ignition properties [18].

2.1 Determination of the metallic components of the raw materials

0.2 g of the ground samples (coal and groundnut shell) were weighed into a crucible. 10 ml of aqua regia (prepared by mixing concentrated HCl and HNO_3 at a ratio of 3:1) was added into the crucible, and 5 ml of hydrofluoric acid was added. The whole mixture was thoroughly stirred using a spatula. The crucible was properly covered and put into an oven set at 100ºC for 2 hours, after which the sample got digested. It was allowed to cool down. The mixture was transferred using a funnel into a 250-ml volumetric flask. The crucible was rinsed with deionized water and then poured into the volumetric flask and made up to 250ml mark of the volumetric flask. A portion of the mixture was then sent for AAS analysis [19].

2.2 Proximate analysis of the groundnut shell

Moisture content, volatile matter, ash content, carbon content, and fixed carbon content were evaluated according to standard methods [20].

2.3 Bio-coal briquette formulation.

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The briquettes were produced using a manual hydraulic briquetting machine with cylindrical moulds. After the preliminary characterization of the raw materials, bio-coal briquettes were formulated using different percentages of groundnut shell and coal. The coal's portion of the biomass was 100:0, 90:10, 85:15, 80:20, 75:25, and 70:30. While the quantity of calcium hydroxide applied was 20% of the whole briquette. After production, the briquettes were sun-dried for 7 days before analysis.

Table 1. Bio-coal briquette formulation

Raw materials						
Coal (%)	100	90	85	80	75	70
Biomass load (%)	0	10	15	20	25	30
Bio coal Briquette Formulation						
Coal (g)	280	252	238	224	210	196
Groundnut shell powder (g)	0	28	42	56	70	84
Cassava starch (g)	70	70	70	70	70	70
Calcium hydroxide (g)	14.00	12.60	11.90	11.20	10.5	9.80
Water (ml)	250	250	250	250	250	250
The formulated ground nut shell bio coal briquettes						

2.4 Characterization of the bio-coal briquettes samples

2.4.1 Determination of Ignition Time

The period of time it requires a flame to bring a briquette to ignition point is known as the ignition time. With a cigarette lighter set to produce a steady light, the sample briquettes were lit at the base's edge. The time it took for each briquette sample to ignite was noted as the sample's ignition time. For each sample, as well as the typical time taken, the test was done twice [21].

2.4.2 Determination of Density

Density illustrates the structural packing of the molecules of the substance in a given volume. Since the briquettes are cylindrical and have equal diameters (3.90 cm), the various heights of each were measured using veneer calipers. The volume was evaluated using $\pi r^2 h$. The density was computed as the ratio of mass to the volume of the briquette [22].

2.4.3 Determination of compressive strength of the briquette samples

The compressive strength is the force required to crush or break a material. It determines how the briquettes can be handled. A briquette sample with a good compressive strength can easily be transported, packed, and handled.

The compressive factor of the briquette samples was determined using a compressive strength testing machine, Model 2914. This machine is 1000kN capacity capable of compressing non-metallic materials. It is powered by electricity, but hydraulically operated. The length and width dimensions of the specimen were measured and recorded. The machine was switched from the mains and allowed to warm up for about 3 minutes. The samples was then put on the movable bed, and the control lever was applied upward to bring contact between the upper fixed bed and the movable lower bed on which the samples were sitting. The reading was taken immediately crack was noticed in the specimen, an indication that the specimen has been compressed. The value of the reading recorded from the machine is the compressive force, or test force. The strength was calculated using the formula below [23]. The unit is given as N/mm^2.

$$\text{Compressive strength} = \frac{\text{compressive force/ test force (Ft)}}{\text{Cross sectional area of the sample (Ac)}}$$

Where cross sectional area = length × width.

2.4.4. Water boiling tests of the briquette samples

The time elapsed for a definite quantity of briquettes (100 g) to boil a specific quantity of water. This will indicate the briquette sample that will cook food faster. 1litre of water was poured into a kettle and the briquette were ignited in a specified stove. The time taken for a briquette sample to boil the water was noted and recorded [24].

3.0 RESULTS AND DISCUSSION

Groundnut shells, also known as peanut shells, are the outer protective covering of the peanut, or groundnut, seed. They are composed of a combination of cellulose, hemicellulose, and lignin, which are types of structural carbohydrates found in plant cell walls. Additionally, groundnut shells contain small amounts of protein, fat, and mineral matter [25]. The groundnut shells were carbonized to produce bio-coal, which was then mixed with a binder and pressed into briquettes. The prepared briquettes were characterized for their physical and fuel properties, such as physical durability, stability, relaxed density, and water resistance. It was observed that the coloration of the briquettes varied depending on the quantity of groundnut shell added.

Table 2. The proximate composition of groundnut shell

Proximate constituent	%
Carbohydrate	21.2
Cellulose	65.7
Protein	7.3
Lipids	1.2
Mineral matter	4.5

However, the proximate composition of groundnut shells varies somewhat depending on the specific variety of peanut and the growing conditions, but in general, they are composed of: carbohydrate, cellulose, protein, fat, and ash.

The shells are also characterized by a relatively low caloric value, as they are mostly composed of structural carbohydrates. They can then be used for a variety of other purposes, including as a biofuel, a soil amendment, and a source of natural fibers for use in textiles and other products [26].

Table 3. Elemental composition

Cation	**Groundnut shell (%)**	**Coal (%)**
Ca^{2+}	0.651	0.115
Mg^{2+}	ND	0.020
Al^{3+}	0.029	0.074
Na+	0.203	0.126
K+	0.323	0.081
Cu^{2+}	0.043	0.028
Zn^{2+}	0.004	0.073
Mn^{2+}	0.041	0.089
Pb^{2+}	0.188	0.338
Ni^{2+}	0.031	0.242
Cr^{2+}	ND	0.305
As^{2+}	0.003	0.129
S	0.007	0.930

ND = Not detectable

From Table 3 above, some values are higher in coal than in groundnut shell. During combustion, some of these elements will be deposited in the ash [27]. Therefore, it is expected that the ash composition of the coal will be higher than that of the groundnut shell. Also, it can be seen that the percentages of As and Pb, which are toxic pollutants, are higher in coal than in groundnut shell. The sulphur content of coal is 0.93%, compared to 0.007% of groundnut shell respectively.

Therefore coal has tendency of emitting sulphur (IV) oxide into the atmosphere than the other during combustion.

Basically groundnut shells do not generally contain significant amounts of metallic elements [26]. However, they may contain trace amounts of metallic elements as impurities and are not considered a significant source of these elements. In general, groundnut shells are not a good source of metallic elements and are not used for the extraction of these elements. If interested in the metallic composition of groundnuts themselves as opposed to their shells, it is worth noting that groundnuts do contain small amounts of metallic elements. These elements are typically present in the form of trace minerals, which are essential for human health in small amounts.

Table 4. Proximate estimations

Parameter	Groundnut shell powder	Coal
Moisture content (%)	10.30	6.10
Ash content (%)	6.00	14.00
Volatile matter (%)	54.70	23.00
Fixed Carbon (%)	29.00	56.90
Carbon content (%)	26.00	64.30

Proximate analysis is a technique used to determine the chemical composition of a substance. It involves the analysis of the various components of a substance, such as its moisture content, ash content, fat content, and protein content [28]. The proximate analysis of groundnut shell powder and coal can provide information about the potential uses and applications of these materials.

A proximate analysis of groundnut shell powder and coal would involve the determination of the moisture content, ash content, fat content, and protein content of these materials. The moisture content refers to the amount of water present in the sample, while the ash content is the amount of inorganic material present in the sample. The fat content refers to the number of lipids present in the sample, while the protein content refers to the number of amino acids present in the sample. A comparative study of the proximate analysis of groundnut shell powder and coal will provide insights into the potential uses and applications of these materials. The high cellulose and lignin content of groundnut shell powder may make it a suitable biofuel, while the high carbon content of coal may make it a valuable fuel for electricity generation [29]. Additionally, the proximate analysis of these materials could provide information about their potential environmental impacts, as the production and use of fossil fuels can contribute to greenhouse gas emissions.

Hence, groundnut shells have a higher moisture content compared to coal. According to the literature, the ideal moisture content for the complete combustion of the briquettes should be between 10 and 15 percent to improve storage and prevent rotting and decomposition [30]. Additionally, groundnut shells have a higher value of volatile matter than coal, which is consistent with literature which states that biomass usually has a higher volatile matter content than coal. Results also indicate that coal has a higher ash content than groundnut shells. Literature suggests that biomass generally has less ash content than coal and that the ash in biomass is made up of elements necessary for plant growth, whereas coal ash is made up of minerals. Lastly, it is seen that the carbon factor of coal is higher than that of groundnut shells, which is expected [30].

Table 5. The effects of biomass load on the specific characteristics of the briquette samples

Biomass load (%)	Moisture content (%)	Ash content (%)	Density x 10^2 (kg/m^3)	Ignition time (mins.)	Compressive strength (N/mm^2)	Boiling Time (mins.)
0	6.00	11.7	10.0	18	1.31	18
10	5.50	12.9	9.5	15	1.14	24
15	5.50	12.3	9.3	13	1.08	22
20	6.50	11.6	9.2	11	0.98	20
25	7.50	11.2	9.1	10	0.93	19
30	7.00	9.10	9.0	8	0.83	12

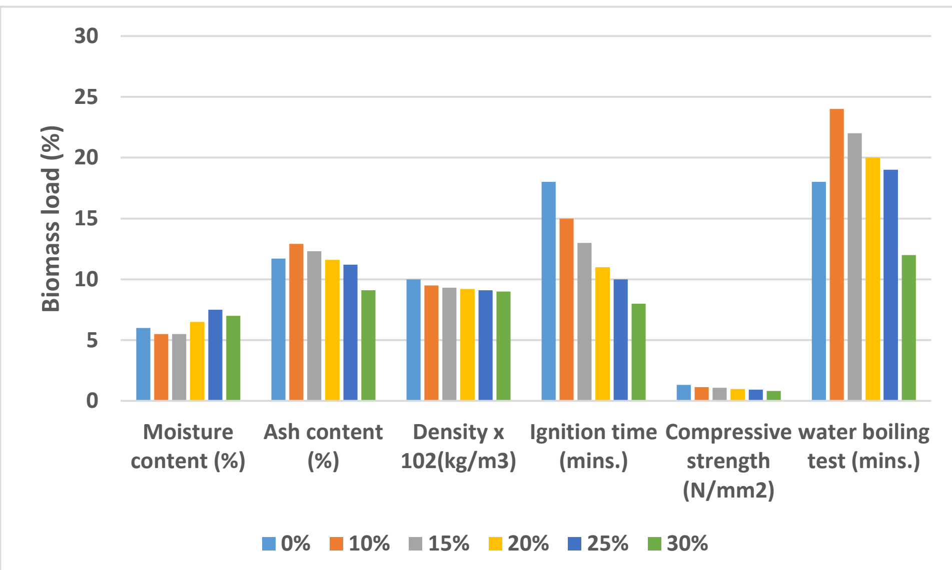

Figure 2. Graphical illustrations of the effects of biomass load on the specific characteristics of the briquette samples

3.1 Effect of biomass on the moisture content of the briquette samples

Biomass is a type of renewable energy source that is derived from organic materials, such as wood, agricultural crops, and animal waste. These materials can be used to produce a variety of products, including fuel briquettes. The moisture content of the biomass used to make briquettes can have a significant effect on the quality and performance of the final product. The effect of biomass on the moisture level of the briquette samples are indicated in Table 5. The moisture percentage of the briquette without biomass (control) is 6.00%. For the groundnut shell-coal briquettes; the moisture content decreases from 10% - 15% and increases from 20% - 30%. When the moisture content of the biomass is too high, it can reduce the density and strength of the briquettes, making them more prone to breaking and less efficient as a fuel source. On the other hand, if the moisture content is too low, the briquettes may be dry and crumbly, making them difficult to handle and transport [31]. In order to produce high-quality briquettes, it is important to carefully control the moisture content of the biomass. This can be done through a variety of methods, such as drying the biomass in a kiln or using a moisture meter to measure the moisture content of the raw material before it is processed into briquettes.

3.2 Effect of biomass on the ash content of the briquette samples

The effect of biomass on the ash content of the briquette samples are indicated in Table 5. The ash content of the briquette without biomass (control) is 11.7%. The value of the ash content decreases from 10% - 15% and increases from 20% - 30%. The ash content of biomass briquette samples is affected by several factors, including the type of biomass used and the conditions under which the briquettes are made. One factor that can influence the ash content of biomass briquettes is the type of biomass used. Different types of biomass have varying levels of ash content, and this can affect the overall ash content of the briquette samples.

Another factor that can impact the ash content of biomass briquette samples is the conditions under which the briquettes are made. The ash content can be influenced by the temperature and duration of the briquetting process, as well as the moisture content of the biomass [32].

If the temperature and duration of the briquetting process are not optimal, the ash content of the briquettes may be higher. Similarly, if the moisture content of the biomass is too high, the ash content may also be higher.

3.3 Effect of biomass on the density of the briquette samples

The results demonstrate that the density of the samples increases as the biomass load increases, which would facilitate their ease of transportation.

Density is a characteristic of importance for biofuel briquettes. Generally, denser biomass materials, such as wood, will lead to denser briquettes when compared to less dense materials, such as straw or grass.

The density of a briquette sample can be affected by various factors. The type of biomass used in its production is one of these factors. Additionally, moisture content of the biomass has an effect, lower moisture content leads to denser briquettes while higher moisture content results in less dense briquettes [30].

The compaction pressure applied during the briquetting process also influence the density, higher pressure results in denser briquettes while lower pressure results in less dense briquettes [33]. Finally, the use of binders or additives during the briquetting process can affect the density of the briquettes [34]. Certain binders or additives can increase the overall density by holding the biomass more tightly together.

3.4 Effect of biomass on the ignition time of the briquette samples

The ignition time of a briquette sample, which refers to the amount of time it takes for the briquette to ignite and start burning when exposed to an ignition source, decreases with an increase in biomass load. The ignition time can be affected by a variety of factors, including the composition and density of the briquette, the moisture content of the briquette, and the size and shape of the briquette. One factor that can affect the ignition time of a briquette is the type of biomass used to make the briquette [35]. Different types of biomass have different properties that can influence the ignition time of the briquette. As a result, briquettes made from wood may have a shorter ignition time than briquettes made from other types of biomass.

The moisture content of the biomass can also affect the ignition time of the briquette. Briquettes that are too moist may be more difficult to ignite, as the moisture can interfere with the ignition process. On the other hand, briquettes that are too dry may ignite more easily, but may also burn more quickly and produce less heat [36].

3.5 Effect of biomass on the compressive strength of the briquette samples

Biomass reduces the compressive strength of the briquettes, as the sample with the least amount of biomass has the highest value of compressive strength, and this is due to the fact that there is no biomass in it; hence, the coal particles are closely packed together. The higher the biomass load, the lower the compressive strength**.** The compressive strength of a briquette is determined by the amount of force required to break it when it is compressed. Biomass, or organic matter that can be used as a fuel, is often used to make briquettes. Different types of biomass have different physical and chemical properties, which can affect the compressive strength of the resulting briquette [37]. The moisture content of the biomass can also affect the compressive strength of the briquette. If the biomass is too moist, it may not bind well, and the briquettes may be weak. On the other hand, if the biomass is too dry, it may not have enough binding strength, and the briquettes may also be weak [38]. In addition to the type and moisture content of the biomass, other factors that can affect the compressive strength of briquette samples include the size and shape of the briquette, the amount of pressure used to compress it, and the presence of any additives or binders that are used to improve its strength.

3.6 Effect of biomass on the water boiling test.

The time it takes to boil 1 liter of water with 100 g of coal briquettes (control) is 18 minutes. It takes a longer period of time to evaporate water with bio-briquettes, which in turn decrease from 10% to 25 %(> 15% > 20% > 25%), while 30% is smaller than the control. The lesser value of the control may be due to the higher calorific magnitude of the coal which produces higher heat energy, hence lesser the time required to boil water. One way that biomass can affect the water boiling test is through its heating value, or the amount of energy that is released when it is burned. Different types of biomass have different heating values, which can impact the amount of time it takes to boil water. Another way that biomass can affect the water boiling test is through its moisture content. Biomass with a high moisture content, such as fresh wood or wet grass, can take longer to burn and may produce less heat than dry biomass [39].

4.0 CONCLUSION

Groundnut shells, a waste material, were utilized as a source of biomass and blended with bio-coal to produce briquettes. The production process involved blending groundnut shells and bio-coal, binding the mixture with a starch binder, and compressing the mixture into briquettes using a manual press. The characterization of the briquettes revealed that they had a high calorific value, which is significant compared to that of traditional coal. The briquettes also had a low moisture content, which indicates that they are suitable for use as fuel. Additionally, the briquettes had a high carbon content, which is important for producing high-energy fuel.

The use of groundnut shells in the production of briquettes offers an environmentally sustainable solution to the problem of agricultural waste disposal. Furthermore, by using bio-coal as a binder, it is possible to create a fuel that is more sustainable and renewable than traditional coal.

The results of this research suggest that groundnut shell bio-coal blended briquettes are a viable alternative to traditional coal and can be used for a variety of applications, such as cooking, heating, and power generation. In addition, this study also provides a way to utilize the agricultural waste products, reduce the pressure on the environment by disposing of them, and also producing a clean energy source. In the future, it would be valuable to explore different ratios of groundnut shells and bio-coal in the production of briquettes, as well as other binding agents that may be used in place of starch. Additionally, further research could focus on the development of automated presses for the production of briquettes, as well as studying the storage and transportation of the briquettes. Eventually, this research has provided a promising solution to both waste disposal and energy production problems by utilizing groundnut shells and bio-coal to produce briquettes. These briquettes have a high calorific value and are suitable for use as fuel, making them a viable alternative to traditional coal. The study will have a wide range of applications in energy production and waste management while also contributing to sustainable development.

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