

Comparative Assessment of Combustion Properties of Carbonized and Non-carbonized Briquettes from Sawdust

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Abstract

Sawdust is a by-product of woodwork operations such as sawing, sanding, milling, planning and routing. It is mainly composed of fine chippings of wood. This study compares and contrast the properties of carbonized and non-carbonized briquettes made from sawdust. Eight (8) different briquettes samples were synthesized (four (4) for non–carbonized and four (4) for carbonized briquettes) with equal binder concentrations of 3.0, 5.0, 7.0 and 9.0 % w/w respectively. The briquettes produced were labelled A, B, C and D for the non–carbonized briquettes and E, F, G and H for the carbonized briquettes respectively. Tapioca starch was used as the binding agent. The combustion properties analyzed were ash content, moisture content and volatile matter. The fixed carbon content, calorific value, bulk density and briquettes yield were also determined. The carbonized briquette samples were found to have lower ash content, moisture content and volatile matter with average values of 16.95 %, 6.06 %, and 20.70 % w/w respectively, compared to that of the non-carbonized briquette with corresponding average values of 23.14 %, 7.94 % and 23.74 % w/w respectively. The carbonized briquettes were adjudged better fuel having higher carbon content, calorific value and bulk density with average values of 56.30 wt%, 26.26MJ/kg and 184.41kg/m^3 respectively, compared to that of the non-carbonized briquette with corresponding average values of 45.29 wt%, 23.47MJ/kg and 173.61kg/m^3 respectively. More also, the carbonized briquettes exhibit slightly a higher briquette yield than the corresponding non-carbonized briquettes produced. Generally, the results indicate that carbonized briquettes are better fuels than the corresponding non-carbonized briquettes. Furthermore, the results point to the viability of using waste sawdust for briquette manufacture as alternative energy source for domestic and local small-scale industries applications.

Keywords: briquettes, sawdust, carbonize, non-carbonize, binder, tapioca

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1. Introduction

Among the various available energy resources, the most used resource worldwide is fossil fuel. Economic growth, urbanization, population increase and global energy needs has contributed to overdependence and increased demands of fossil fuels, which lead to the growing rise in the price of fuel particularly in the developing countries of Africa and Asia, such as Nigeria. In addition, the rising trend in fossil fuel usage has been linked to the deteriorating effects of global warming caused by the resulting emissions due to fossil use. Consequently, effort is being targeted towards promoting and exploration of alternative sources of eco-friendly energies such as biomass briquettes (Bello and Onilude, 2020). Biomass, a naturally inexhaustible domestic energy source is seen as the most encouraging and promising energy choice to relieve greenhouse gas (GHG) emission.

Waste agricultural biomass is regularly underused, even more so there is quick increment in volume and kinds of waste biomass created worldwide because of serious agrarian exercises in the wake of populace development and improved expectations for everyday comforts. In Nigeria especially, with a population estimate of over 200 million people (UNFPA, 2022), agriculture is the primary sector of the economy contributing over 21% of the gross domestic product (GDP). In addition, agriculture employs two–third of the country`s entire labour force (FAO Nigeria, 2020).

With pressing challenges in energy security, particularly in Nigeria, there is high potential of biomass briquette from agricultural wastes such as sawdust becoming a preferred substitute fuel for variety of energy uses such cooking and commercial process heat. This could make available and affordable domestic energy substitute to consumers that is easily accessible which also support a benign environment through stemming deforestation and reduced emission of greenhouse gas (GHG) to the atmosphere.

2. Biomass

Biomass has been in use since people first began burning wood to cook food and keep warm. Biomass refers to non-fossil biodegradable organic material from plant, animal and microbial origin. Biomass materials include food crops, grassy and woody plants, products, by-products, residues and wastes from agricultural and forestry activities; non-fossil and biodegradable fractions from municipal and industrial wastes (Zubairu and Gana, 2014; Perea-Moreno, 2019). Wood is still the largest biomass energy resource today.

Biomass is clean, renewable and environmentally friendly energy. It has less sulfur, nitrogen and ash, which cause SO_2 and NOx formation, compared to fossil fuels (Suttibak and Loengbudnark, 2018). Traditionally, biomass energy use is obtained by converting organic chemical energy through different processes such as combustion, anaerobic digestion, fermentation, gasification and pyrolysis (McKendry, 2002). Biomass energy can be converted into liquid, gaseous and solid fuels as well as other feed stocks and products. Gaseous biomass fuel includes anaerobic digestion (methane production) and biomass gasification. Liquid biomass fuel mostly refers to fuel ethanol and biodiesel produced by bio-mass resources, and can be used to partially replace the petroleum to produce gasoline and diesel. Solid biomass fuel is divided into direct combustion of biomass fuel and densified solid biofuel like briquettes. Among them, densified solid biofuel has an extensive market and bright projections (Demirbas, 2010).

According to (Demirbas, 2010), biomass can be classified into four different categories: wood and woody biomass, herbaceous biomass, aquatic biomass and animal and human waste biomass. Table 1 shows biomass classification groups, varieties and species. Sawdust (or wood shavings) is a by-product or waste product of woodworking operations such as sawing, sanding, milling, planning, and routing. It is composed of small fine chippings of wood. These operations can be performed by woodworking machinery, portable power tools or by use of hand tools. Wood dust is also the byproduct of certain animals, birds and insects which live in wood, such as the woodpecker and carpenter ant. In some manufacturing industries it can be a significant fire hazard and source of occupational dust exposure (Mwasha and Ramdhanie, 2019).

Generally, biomass is naturally abundant and presents a renewable energy opportunity that could serve as an alternative to fossil fuel; In Nigeria, the huge volume of agricultural waste generated annually, coupled with the decreasing availability of wood fuel has necessitated concerted effort to look for efficient ways of harnessing these wastes for energy generation. Direct combustion of raw agricultural waste as fuel feedstock has some obvious disadvantages including difficulty in controlling the burning rate of the biomass, difficulty in mechanized process charging, low heat density, difficulty in stock handling and transportation as well as large storage requirements. Most of these problems are associated with the low bulk density of the agricultural waste. One approach to checkmate these setbacks and efficiently utilize agricultural wastes as fuel is by their densification to produce briquettes (Zubairu and Gana, 2014).

3. Briquettes

A briquette is a block of compressed or extruded shredded combustible biomass materials (e.g. charcoal, sawdust, wood chips, peat or paper, etc.) which can be used as fuel and kindling to start and sustain fire. The term is derived from the French word *brique*, meaning *brick* (Ugwu, 2016). The biomass materials are often held together via the aid of a binding agent such as starch, even though application of pressure may at times be adequate to keep the materials together (Shyamalee, 2015).

Table 1. Typical Biomass Categories and Representative Species (Demirbas, 2010)

Biomass Category	Varieties and Species
Wood and woody biomass	Coniferous or deciduous; Angiosperms or gymnosperms; Stems, branches, foliage, bark, chips, lumps, pellets, sawdust, sawmill and others from various wood species.
Herbaceous biomass	Grasses and flowers (alfalfa, arundo, bamboo, brassica, cane, cynara, silver grass, switch grass, timothy, others); straws (barley, bean, flax, corn, mint, oat, rape, rice, rye, sesame, sunflower, wheat, others); other residues (fruits, shells, husks, hulls, pits, pips, grains, seeds, coir, stalks, cobs, kernels, bagasse, food, fodder, pulps, cakes, etc.).
Aquatic biomass	Marine or freshwater algae; macroalgae (blue, green, blue-green, brown, red) or microalgae; sea weed, kelp, lake weed, water hyacinth, etc.
Animal and human waste biomass	Bones, meat-bone meal; various manures, etc.

Briquettes produced from agro-residues are fairly good substitute for coal, lignite and firewood. Handling, transportation and storage costs of agro-residues are drastically reduced if converted in to briquettes due to density enhancement. For instance, density increase of more than five orders of magnitude is typically achieved when agricultural wastes are converted into briquettes (García, et al., , 2019).

Biomass briquettes are produced from agricultural waste and are a suitable replacement for fossil fuels such as oil or coal. Briquette are applied to heat boilers in manufacturing plants and have wide applications in developing countries. Biomass briquettes are a technically renewable source of energy and produce less carbon emissions than traditional coal briquettes (Kpalo, et. al., 2020).

3.1 Non-carbonized briquettes

Non-carbonized briquettes are produced from waste materials that are not carbonized such as sawdust and waste paper. Non-carbonized briquettes are produced from waste materials that are partially decomposed and then dried and can be manually produced, with manual presses, or with a mechanized mold or extruder, while mixing the biomass feedstock with water and a binder and consequently drying them.

A popular biomass briquette emerging in developed countries takes a waste produce such as sawdust, compresses it and then extrudes it to make a reconstituted log that can replace firewood. It is a similar process to forming a wood pellet but on a larger scale. There are no binders involved in this process. The natural lignin in the wood binds the particles of wood together to form a solid. Burning a wood briquette is far more efficient than burning firewood. Moisture content of a briquette can be as low as 4%, whereas green firewood may be as high as 65% (Nwaokocha, et. al., 2019).

The use of biomass briquettes is predominant in the southern parts of India, where biomass briquette are replacing coal and furnace oil. Use of biomass briquettes can earn carbon credits for reducing emissions in the atmosphere. Biomass briquettes also provide more calorific value/kg and save around 30-40 percent of boiler fuel costs (Patil et. al., 2012).

3.2 Carbonized briquettes

These are made from waste materials that have undergone carbonization such as charcoal dust, or carbonizing non-carbonized briquettes. The charred biomass is then grinded, mixed with a binding agent and compressed or extruded to produce the desired briquettes.

4. Material and Methods

4.1 Materials

Waste sawdust biomass was collected from local wood work located along Bama Road in Maiduguri, Borno State. Tapioca starch was obtained from a local market in Maiduguri, Borno State. Briquette mould used was fabricated locally using a PVC pipe (length of 9.50cm and internal diameter of 4.5cm). All other equipment used; furnace, oven, digital weighing balance, desiccator, crucibles and sieve were all accessed in the Department of Chemical Engineering laboratory, University of Maiduguri.

4.2 Methods

4.2.1 Carbonized Briquettes Feedstock Preparation and Carbonization

Sawdust was first sun dried to reduce its moisture content. Initially, the moisture content was estimated to be around 75% w/w, after drying, the final moisture content of the material was recorded as 27 % w/w. The dried sample was carbonized in an electric muffle furnace at a temperature of 450^{o}C for 25 minutes. The carbonized saw dust was then grinded into fine particles and then sieved using a BSS8 sieve (200-micron sieve). The sieved pulverized charcoal was measured and divided into four (4) portions of 300g each.

4.2.2 Binding and Mixing

Four different grades of binder formulations were produced by dissolving 30, 50, 70 and 90g of tapioca starch in 500ml of water. At first, the tapioca starch was dissolved in 100 ml of cold water to form a paste, and 400 ml of water was added and brought to boil. The paste was mixed with the boiling water gradually until a gelatinized starch solution was formed. While the binder solution was still warm, the finely carbonized sawdust powder was added and thoroughly agitated until a thick homogeneous compound was obtained.

4.2.3 Briquetting and Drying

The mixed carbonized compound obtained was then dispensed and pressed in a manual briquette pressing mould and then allowed to dry under ambient conditions.

4.2.4 Non-carbonized Briquettes

The procedure for producing the non–carbonized biomass briquette was similar to that of the carbonized briquette. The only difference is the absence of the carbonization process. For the non–carbonized biomass briquette, the sample was sun dried to reduce the moisture content (estimated initial moisture was 75% w/w and the final moisture content was 27% w/w) content and then grinded into fine particles. The grinded fine particle was then mixed with the already prepared binder solution to form a thick brown compound. The mixed compound was dispensed and pressed in a manual briquetting pressing mould and allowed to dry.

4.3 Briquettes Characterization

The produced biomass briquette was characterized by determining the following properties: ash content, moisture content, volatile matter, briquette yield, bulk density, fixed carbon content and calorific value.

4.3.1 Determination of Ash Content

To measure the ash content of the briquette, a sample in a crucible was heated in a muffle furnace at 650ºc for 90 minutes without a lid. The crucible was then removed, cooled first in air, then in desiccator and weighed. The residue was reported as ash on percentage basis using equation (1) (Raju et al., 2014).

$$Ash\ Content = \frac{W3-W1}{W2-W1} \times 100 \qquad (1)$$

Where;
W_1 = weight of crucible (g)
W_2 = weight of crucible + sample (g)
W_3 = weight of crucible + ash (g).

4.3.2 Determination of Moisture Content

Typically, moisture content is determined via thermogravimetric approach (hot air oven drying method) i.e., by weight loss on drying, in which the sample was heated at 105ºC to 110ºC for one hour up to a constant weight loss evaluated using equation (2) (Raju et al., 2014).

$$Moisture\ Content = \frac{W2-W3}{W2-W1} \times 100 \qquad (2)$$

Where;
W_1 = weight of crucible (g)
W_2 = weight of crucible + sample (g)
W_3 = weight of crucible + sample after heating (g).

4.3.3 Determination of Volatile Matter

To determine the volatile matter, a dried sample in the crucible was covered with a lid and placed in an electric muffle furnace maintained at 905ºC for 7 minutes. The crucible was cooled first in air then inside a desiccator and weighed again. Loss in weight was reported as volatile matter on percentage basis using equation (3) (Raju et al., 2014).

$$Volatile\ Matter = \frac{W2-W3}{W2-W1} \times 100 \qquad (3)$$

Where;
W_1 = weight of crucible (g)
W_2 = weight of crucible + sample (g)
W_3 = weight of crucible + sample after heating (g).

4.3.4 Determination of Briquette Yield

The briquette yield can be determine using equation (4) (Islam 2011):

$$Briquette\ Yield\ (BY\ \%) \frac{\text{Charcoal weight}}{\text{Biomass Weight}} \times 100 \quad (4)$$

4.3.4 Determination of Bulk Density

The bulk density is the total mass per unit volume calculated from equation (5) (Bhagwanrao and Singaravelu, 2014).

$$\rho_b = \frac{M}{V} \quad (5)$$

4.3.5 Determination of Fixed Carbon

The fixed carbon content of the briquette was determined by subtracting the summation of moisture, volatile matter and ash from 100 as illustrated in equation (6) (Raju et al., 2014).

$$FCC = 100\% - (MC\% + VM\% + AC\% \quad (6)$$

4.3.6 Determination of Calorific Value

The heating value was calculated using equation (7) (Emerhi, 2011).

$$HV = 2.326(147.6C + 144V) \quad (7)$$

Where: C = percentage fixed carbon and V = percentage volatile matter

5. Results and Discussions

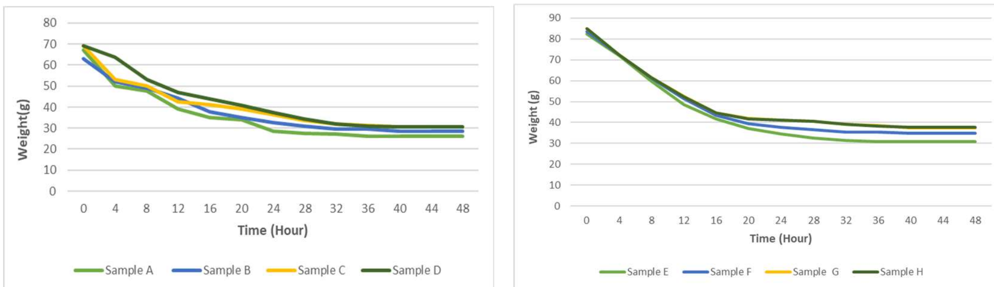
Eight (8) different briquettes samples were synthesized (four (4) each for non–carbonized briquettes and carbonized briquettes) with binder concentration of 3.0, 5.0, 7.0 and 9.0 % w/w respectively. The briquettes produced were labelled A, B, C and D for the non–carbonized briquettes and E, F, G and H for the carbonized briquettes respectively. Comparative assessment was carried out on the samples; the samples were first dried and analyzed to tests for ash content, moisture content, volatile matter, fixed carbon content and bulk density. The calorific value was calculated from the data obtained for the fixed carbon content and volatile matter. Figure 1 shows the representative pictures of the non-carbonized and carbonized briquettes.

(a) (b)

Figure 1. Synthesized briquettes (a) non-carbonized (b) Carbonized

5.1 Briquettes Drying

Figure 2 shows the drying profiles of the briquette samples until a constant weight was obtained.



(a)
(b)

Figure 2. Briquettes Drying Curves (a) non-carbonized (b) Carbonized

Figure 2 shows that the drying curves are characteristics of weight loss of the briquette with time due to loss in moisture content present in the sample as time evolves. It could be seen that for both non-carbonized and carbonized briquettes, higher the binder concentration promotes faster drying with faster attainment of constant weight of briquettes. The carbonized briquettes tend to dry faster than the non-carbonized briquettes for a given binder concentration. This is likely due to the fact that the carbonization process has already reduced the moisture content of the briquette samples, hence dried easier compared to the non-carbonized briquettes sample.

5.2 Briquettes Characterization

Table 2. Non-carbonized briquettes samples properties

PROPERTY	SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D
Ash Content (wt %)	28.97	22.61	21.73	19.23
Moisture Content (wt %)	8.02	8.11	7.68	7.93
Volatile Matter (wt %)	28.25	24.43	20.0	21.88
Fixed Carbon Content (wt %)	34.76	44.85	50.59	50.96
Calorific Value (MJ/kg)	21.40	23.58	24.07	24.82
Bulk Density (kg/m^3)	146.22	174.22	186.39	187.61
Briquette Yield (kg/kg)	0.88	1.05	1.12	1.13

Table 3. Carbonized briquettes samples properties

PROPERTY	SAMPLE E	SAMPLE F	SAMPLE G	SAMPLE H
Ash Content (wt %)	17.54	17.41	16.43	16.41
Moisture Content (wt %)	5.33	6.45	6.81	5.63
Volatile Matter (wt %)	22.14	20.53	20.95	19.18
Fixed Carbon Content (wt %)	54.99	55.61	55.81	58.78
Calorific Value (MJ/kg)	26.30	25.97	26.18	26.60
Bulk Density (kg/m^3)	153.55	174.35	187.50	188.10
Briquette Yield (kg/kg)	0.92	1.05	1.13	1.13

5.2.1 Determination of Ash Content

The ash content of the briquette charcoal is the amount of ash that remains after the charcoal is burnt or incinerated. The ash content is measured to determine how much material (ash residue) remains after the briquette is combusted, i.e., the non-combustible component of biomass. The ash content was determined for the non-carbonized briquette samples A, B, C and D as 28.97, 22.61, 21.73 and 19.23% w/w respectively, while for the carbonized briquette samples E, F, G and H as 17.54, 17.41, 16.43 and 16.41% w/w respectively. The literature (Pallavi et al., 2013) recommended ash content for good quality briquettes as 3-4%. The results indicates that the non-carbonized briquette exhibits higher ash content with the average of 23.14% compared to the average of 16.95% for the carbonized briquettes. The briquette formulated in this work exhibit higher ash content than the recommended limit likely due to the influence of the tapioca starch that was used as the binding agent. More also, it could be seen that the binder concentration influences the ash content of the briquettes. According to (Raju, et. al., 2014) as ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilization than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. Chaney (2010), asserts that the higher the fuel's ash content, the lower is its calorific value.

5.2.2 Determination of Moisture Content

Moisture content is one of the properties which affects the usability and quality of the biomass briquette. The total energy that is needed to bring a briquette up to its pyrolytic temperature is dependent on its moisture content which affects the internal temperature within the briquette due to endothermic evaporation. The moisture content was determined for the non-carbonized briquette samples A, B, C and D are 8.02, 8.11, 7.68 and 7.93% w/w respectively, while the carbonized briquette samples E, F, G and H are 5.33, 6.45, 6.81 and 5.63% w/w respectively. Moisture content for good quality briquettes according to literature recommendations is 5-10% (Pallavi et al., 2013). The moisture content for the produced briquettes all fall within the range of the literature recommendation. The results show that the non-carbonized briquettes exhibit higher moisture content with the average of 7.94% compared to the average of 6.06% for the carbonized briquette and the reason for that can also be attributed the carbonization process that occur during the production of the carbonized briquette as organic molecules are mostly driven off. According to Chaney (2010) lower moisture content of briquettes implies a higher calorific value.

5.2.3 Determination of Volatile Matter

Volatile matter is a measure of the non-water gases formed from the briquette sample. The volatile matter was determined for the non-carbonized briquette samples A, B, C and D as 28.25, 24.43, 20.00 and 21.88% w/w respectively, while for the carbonized briquette samples E, F, G and H are 22.14, 20.53, 20.95 and 19.18% w/w respectively. Biomass generally contains a high volatile matter content of around 70% to 86% (Raju et al., 2014). This makes biomass a highly reactive fuel giving a faster combustion rate than other fuels such as coal (Tamilvanan, 2013). For the produced non-carbonized briquette, the maximum volatile content recorded was 28.25 wt % for sample *A* (3.0% binder concentration) while for the carbonized briquette the maximum volatile content recorded was 22.14 wt % for sample *E* (3.0% binder concentration). As reported by (Sheng and Azevedo, 2005) briquette tend to have low volatile content which results in releasing significant amount of smoke and release of toxic gases.

5.2.4 Determination of Fixed Carbon

Fixed carbon is the solid combustible residue that remains after the briquette was heated and the volatile matter is expelled. The fixed carbon content was determined for the non-carbonized briquette samples A, B, C and D as 34.76, 44.85, 50.59 and 50.96% w/w respectively, while for the carbonized briquette samples E, F, G and H as 54.99, 55.61, 55.81 and 58.78% w/w respectively. The fixed carbon content increases with increase in the binder concentration for both the carbonized and non-carbonized briquettes. The highest carbon content recorded was 58.78 % w/w at 9.0% binder concentration (Sample H). The non-carbonized briquette which has higher fixed carbon content indicates that the briquettes will require a long combustion time than the carbonized briquette. The result of the fixed carbon content however does not satisfy the literature recommendation of suitable briquette of 80.5% for domestic use and 86.7% of industrial use (Tamilvanan, 2013). The proportion of fixed carbon can be controlled through maximum temperature and the biomass residence time during the carbonization process and the charcoal produced from high temperature will be higher in fixed carbon than the charcoal produced at lower temperature (Raju et al., 2014).

5.2.5 Determination of Calorific Value

The calorific value also called the heating value or energy value of the briquette is the amount of heat liberated per unit mass of the briquette. It is the measurement of heat or energy released by fuel during the combustion process. The calorific or heating value was determined for the non-carbonized briquette samples A, B, C and D as 21.40, 23.58, 24.07 and 24.82 MJ/kg respectively, while for the carbonized briquette samples E, F, G and H as 26.30, 25.97, 26.18 and 26.60% w/w respectively. As with other properties the binder concentration has an effect on the calorific value of the charcoal briquettes. For the non-carbonized briquette charcoal, calorific value was observed to increase with increase in binder concentration and the average calorific value for the briquette was 23.47MJ/kg, while fro the carbonized briquette, the average calorific value is 26.26 MJ/kg.

5.2.6 Determination of Bulk Density

The bulk density was determined for non-carbonized briquette samples A, B, C and D as 146.22, 174.22, 186.39 and 187.61 kg/m^3 respectively, while for the carbonized briquette samples E, F, G and H as 153.55, 174.35, 187.50 and 188.10% w/w respectively. The bulk density of the non-carbonized briquette charcoal grades was observed to increase with increase in the binder concentration. The highest bulk density recorded was 188.10 kg/m^3 at 9.0% binder concentration for Sample H. The results indicates that saw dust briquettes are less dense compared to other briquettes made from agro-waste such as sugar cane bagasse, teak leaves (Raju et al., 2014) and corn cobs (Zubairu and Gana, 2014).

5.2.7 Determination of Briquettes Yield

The briquette yield obtained for the non-carbonized briquette samples A, B, C, and D were 0.88, 1.05, 1.12 and 1.13 kg briquette/kg binder respectively, and for the carbonized briquette sample E, F, G and H were 0.92, 1.05, 1.13 and 1.13 kg briquette/kg binder respectively. The results show that for both non-carbonized and carbonized briquettes, the yield increases with increase in binder concentration. The increase in the yield is however gradual at high binder concentrations. For the carbonized briquettes, the increase in the yield somewhat insignificant at binder concentrations beyond 7.0%. The initial lower briquette yield at low binder concentration could be attributed to the insufficient amount of binder to stick the materials together, and this tendency increases as the binder concentration increases, thus the observe increase in the yield. There is no appreciable difference in the briquette yield due to the carbonization process as could be seen from the results.

6. Conclusion

Carbonized and non-carbonized briquette fuels were successfully produced from saw dust using tapioca starch as binder. The comparative assessment of the carbonized and non–carbonized briquette produced was conducted by characterization of the produced briquette samples, where their physical properties as well as their combustive properties were determined. From results, it was concluded that carbonized briquettes were found to be better fuel than the non-carbonized briquette.

Furthermore, the results confirmed that fuel briquettes made from sawdust can serve as supplement or alternative energy sources to wood charcoal for domestic and industrial applications.

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