# Production of briquettes from the mixture of sawdust, banana peels and palm fronds using cassava starch as binder

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**Abstract:** Over reliance on fossil fuels has led to environmental pollution and health problems which call for transitioning to a renewable energy system of which briquette is one of the sources. A manually operated briquettes machine was developed which was used to produce briquettes with the mixture of varying proportions of sawdust, banana peels, and palm fronds content as a potential energy source and cassava starch as binder. The sawdust, palm fronds, banana peels, and binder were collected and prepared. They were then mixed at a ratio of 50:25:15:10 for sample A, 40:30:20:10 for sample B, and 30:35:25:10 for sample C to produce briquettes. The briquettes were characterized after production to determine their combustion properties. Fabricated machine has nine mould with dimensions of 330 mm × 330 mm. The force required to compress nine briquettes was determined to be 5195.4 N, and the maximum shear stress in the mould is 0.44 MPa. The results from the analysis revealed that sample C(30:35:25), with the lowest sawdust content, exhibits the highest density of 0.152 g cm$^{-3}$ and the highest ignition time of 40 seconds, while sample A(50:25:15) with the highest sawdust content, demonstrates the shortest ignition time of 35 seconds and the highest calorific value of 24.5 MJ kg$^{-1}$. Sample B shows the lowest density of 0.146 g cm$^{-3}$ and moisture content of 10%, but the shortest burning time of 31 minutes. The most viable mixture of substrates was 50% sawdust, 25% palm frond, and 25% banana peels due to its low ash content and high calorific value amidst many other properties. Briquettes with higher sawdust content provide better energy efficiency and burning performance, highlighting their suitability for domestic fuel applications.

**Keywords**: briquettes, sawdust, banana peels, palm fronds, cassava starch

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## 1 Introduction

With growing development of Nigerian economy, energy consumption is increasing day by day. In Nigeria, over the past decades there has been an over dependence on the usage of fossil fuels in the generation of energy, which has contributed adversely to pollution of the environment (Farooq et al., 2021). The use of fossil fuels is responsible for environmental problems such as global warming and air pollution, which cause health problems and affect the quality of life of populations. The rural masses mostly depend on biomass or kerosene for their energy needs. Gradual price hike in crude oil in international market has greatly affected the rural area dwellers in Nigeria. In order to cushion fuel price hike, they are shifting more to biomass (Emerhi, 2011).

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Deforestation for fuel wood has exacerbated the problem of climate change and global warming. The seriousness of the problem can be sensed by seeing depleting forest reserves. This trend needs to be checked from environment point of view (Ogunjobi et al., 2023). Development of renewable energy sources helps to reduce the degree of dependence on energy imports as well as it can be a tool for curbing carbon emission (Myers et al., 2000). So, emphasis is given to the renewable energy program. The energy requirement in rural households is mainly for cooking and sometimes heating in colder regions which resulted to enormous demand for fuel wood (Oyebanji et al., 2020). The one option could be the densification or briquetting to counter this problem (Grover, and Mishra, 2006). It has a great scope in rural area where there is enormous production of bio waste material every year. This includes rice straw, wheat straw, coconut shells and fibers, rice husks, stalks of legumes, and sawdust. Some of this biomass is just burnt in air, while others like rice husk are mostly dumped into huge mountains of waste (Onuegbu, 2010). Open-field burning has been used traditionally to dispose of crop residues and sanitize agricultural fields against pests and diseases. Instead of burning down these wastes or letting to decompose in open air which raises the problem of Green House Gas (GHG) production, it can be converted to biofuels to produce power either by direct combustion or transforming these loose biomasses to solid fuels (Falemara et al., 2018).

Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure (Sarpong et al., 2019). Three different types of densification technologies are currently in use. The first, called pyrolizing technology, relies on partial pyrolysis of biomass, which is mixed with binder and then made into briquettes by casting and pressing. The second technology is direct extrusion type, where the biomass is dried and directly compacted with high heat and pressure. The last type is called wet briquetting in which decomposition is used in order to break down the fibers. On pressing and drying, briquettes are ready for direct burning or gasification (Afsal et al., 2020). Cassava starch is a good organic binder, and its efficiency in briquette production has been demonstrated. Study conducted by Adegoke (2001) showed that mixture of sawdust and biomass materials when compressed using a specially developed briquetting machine and the briquettes dried either directly in the sun or in an oven. When burned in internally lined stoves, the heat loss to the environment is much reduced and a lot of cooking energy is obtained from a relatively small amount of the sawdust briquettes. Okegbile et al. (2014) investigated the effect of starch and gum arabic as binders in the combustion characteristics of briquette prepared from sawdust of different ratios. Briquettes of sawdust were produced by mixing with different binders and agglomerate using starch paste and gum arabic. They reported that when the calorific value, the volatile matter and flame temperature were determined the results showed that the briquette formed using starch as a binder performed better in all aspect than the gum Arabic when the mixture was compressed at 110 kN using manually operated hydraulic briquette machine and sun dried (Okegbile et al., 2014).

Kebede et al. (2022) discovered that the briquette produced from biomass residues has a mean value of fixed carbon and calorific value that ranged from 38:62 ± 1:53, 41:75 ± 2:14 and 3979:21 ± 232:05 cal $g^{-1}$ 4577:34 ± 397:11 cal $g^{-1}$, respectively. These results buttress that briquettes produced from saw dust residue and the paper pulp binder had better quality of fuel and this could be used as an alternative source of energy and proper waste management option (Ajala et al., 2016). also found out that briquette produced from Cassia siamea significantly gave better performance as solid fuel material than the other species such as Funtumia elastica and Anogeissus leiocarpus. Thus, Cassia siamea wood dust is more efficient for briquette production due to the better performance obtained in all the parameters assessed and a cheaper way of solid fuel utilization in rural areas. Davies (2015) carried out an experiment on sawdust briquettes produced with different types of binders like cassava peels, yam peels and banana peels. He found out that cassava peels bonded briquettes had the best physical and mechanical properties compared to other biomass bonded briquettes.

Falemara et al. (2018) examined the physical and combustion characteristics of briquettes produced from sawdust and agricultural residues as well as heterogeneous combination of the particles. The study affirmed that briquettes produced from sawdust and mixture of groundnut shell, and briquettes produced from sawdust particles alone with 25% starch level had better quality in terms of density, agglomeration, compaction, and combustion properties with respect to high volatile matter, low ash content, high fixed carbon, and high specific heat of combustion. Additionally, the study conducted by Afsal et al. (2020) on the combustion characteristics of fuel briquettes made from vegetables market waste and sawdust showed that the composite briquettes had improved combustion characteristics like higher calorific value and more volatile matter contents than briquettes made from pure vegetable wastes alone.

Sarpong et al. (2019) carried out a research on the properties of briquettes produced from sawdust, corncob, and rice husk. The proximate analysis showed that the mixture of corncob and sawdust briquette had the highest values of volatile matter (71.48%) and fixed carbon content (19.99%), least amounts of ash content (2.29%) and moisture content (6.24%). Mixture of corncob and sawdust also had the highest heating value of 30804.72 kJ $kg^{-1}$. The study carried out by Rajaseenivasan et al. (2016) found out that the performance of the briquettes increases with the increase in pressure. Thus, a pressure of 33 MPa was used to produce briquette from sawdust and neem powder as binder. They discovered that the briquettes produced have increased in strength with a little reduction in burning time compared to briquettes produced with lower pressure. The study carried out by Chukwuneke et al. (2021) on the properties of sawdust and rice husk using cassava starch and clay as binders indicated that composite briquettes of mahogany sawdust and rice husk produced using starch gave the maximum energy value of 5.69 kcal $g^{-1}$ whereas those made with clay gave the least calorific value of 3.35 kcal $g^{-1}$. This indicates that briquette from a composite of Mahogany sawdust/rice husk is, as a result, more appropriate for starting and retaining the fire for cooking and other domestic heating. Ladapo et al. (2020) carried out an experiment on sawdust and maize residues and discovered that energy properties of briquettes produced from maize and sawmill residues are not significantly different. Hence, both briquettes would be good sources of domestic energy. Briquettes were produced from sawdust of Ficus exasperata using binders like top bond, starch, and cow dung, showing varying combustion properties with starch yielding the highest heating value (Ogunjobi et al., 2023).

Having gone through literatures on production of briquettes using different substrates, work has not been carried out on the production of briquettes using the mixture of sawdust, banana peels and palm fronds as substrates, and the cassava starch as binder. The focus of this research work is to produce briquettes from the composite of sawdust, banana peels and palm fronds using cassava starch as binder due to its adhesive and high bonding strength.

## 2 Method

This work was divided into three phases: design and fabrication of the briquetting machine, the briquette production process, and the characterization of the briquettes.

The briquetting machine was designed and fabricated from parts made from mild steel. The steel was selected for the fabrication because mild steel has lots of advantages like availability, strength, high machinability, low cost, high tensile strength etc. The force required to compress the briquette is the first and most important thing that needs to be calculated so it can be used to select the appropriate hydraulic jack.

$$F = PA \quad (1)$$

Where,

$F$ = Force required to compress the briquettes

$P$ = Compaction pressure of 150 kPa to prevent the binder from diffusing out of the mold (Mibulo et al., 2023).

$A$ = Surface area of the briquettes

When a cylinder is subjected to internal pressure, two forces acts upon the cylinder namely:

Circumferential stress:

$$\sigma_c = \frac{total\ pressure}{resisting\ section} = \frac{pd}{2t} \quad (2)$$

Where,

$p$ = Internal pressure (Pa);

$d$ = diameter of the cylinder (m);

$t$ = thickness of the cylinder(m) .

Longitudinal stress:

$$\sigma_l = \frac{total\ pressure}{resisting\ section} = \frac{pd}{4t} \quad (3)$$

Where,

$p$ = Internal pressure;

$d$ = diameter of the cylinder;

$t$ = thickness of the cylinder.

Hence the maximum shear stress: $\tau_{max} = \frac{\left(\frac{pd}{2t}-\frac{pd}{4t}\right)}{2} = \frac{pd}{8t}$

Where,

$p$= Internal pressure;

$d$= diameter of the cylinder;

$t$ = thickness of the cylinder

It is observed that the circumferential stress is greater the longitudinal stress, the thickness of the cylinder wall was obtained and is given as:

$\sigma_c > \sigma_l$

But, since $\sigma_c$ cannot exceed the permissible tensile stress ($\sigma_t$) i.e. $\sigma_c \le \sigma_t$

$$\frac{pd}{2t} \leqslant \sigma_t$$

$$t \geqslant pd/2\sigma_t \quad (4)$$

Where,

$\sigma_c$=Circumferential stress;

$\sigma_l$ = Longitudinal stress;

P = internal pressure;

$d$ = Diameter of the cylinder;

$t$ = Thickness of the cylinder.

The dimensions of the mould:

$D_y$ = diameter of the mould on the y-axis;

$D_x$ = diameter of the mould on the x-axis;

$C_y$ = clearance between cylinders on the y-axis;

$C_x$ = clearance between cylinders on the x-axis.

Hence,

The length of the mould = ($3D_y + 4C_y$);

The width of the mould = ($3D_x + 4C_x$).

**2.1 Design calculations.**

According to Mibulo et al. (2023), the force required to compress a high compressed density of sawdust briquettes was gotten from a compaction pressure of 150 kPa.

Surface area of a briquette sample = $\pi r^2$

$$\pi \times 0.035^2 = 0.003848\ m^2$$

Force required= $150{,}000 \times 0.003848 = 577.3\ N$.

Hence the total force required to compress nine briquettes is calculated as 5,195.4 N

Thickness of cylinder wall;

$$t \geq pd/2\sigma_t$$

where,

$p$ = 150, kPa;

$d$ = 70, mm;

$\sigma_t$ = 550 × 10³, kPa.

$$t \geq \frac{150 \times 70}{2 \times (550 \times 10^3)} = 0.0095\ mm$$

Hence the thickness of cylinder (t) ≥0.0095 mm.

Maximum shear stress in a cylinder;

$$\tau_{max} = \frac{pd}{8t}$$

$$\tau_{max} = \frac{.15 \times 70}{8 \times 3} = 0.44\ MPa.$$

Dimension of mould:

$D_y$ = 70 mm;

$D_x$ = 70 mm;

$C_y$ = 30 mm ;

$C_x$ = 30 mm;

The length of the mould= [3(70)+ 4(30)] = 330 mm;

The width of the mould = [3(70) + 4(30)] = 330 mm.

**2.2 Fabrication of the Briquetting machine**

The briquetting machine was fabricated from parts made of mild steel and consists of the main frame, compaction chamber, base plate, pistons, and the cover plate.

The main frame is essentially the support of the machine, as it houses all the other parts of the machine. It is made from angular bars of mild steel. The compaction chamber is where the compression of briquettes take place, it is made of thick cylindrical pipes of mild steel. The compression chamber must be able to withstand a high amount of pressure for effective briquette production.

The base plate is situated directly below the compaction chamber. The pistons are welded directly onto the plate. The pistons are nine in number, and they were made from cylindrical pipes of mild steel, they are housed on the base plate. The function of the piston is to push the briquettes against the cover plate to compress and density the briquettes. The cover plate has the same dimension as the mould and its purpose is to safely aid in the compression of the briquette by covering the mould during the production of the briquettes.

**2.3 Briquettes production process.**

The following processes and methods were followed in carrying out the production and analysis of the briquettes produced from the mixture of sawdust, banana peels, and palm fronds using cassava starch as binder.

2.3.1 Collection of raw materials

The sawdust, banana peels, and palm fronds were collected from waste sites and local sources. The banana peelings were sun dried then chopped into small pieces. The dry palm fronds used for this experimental analysis were gotten from a palm plantation. The leaves were trimmed off, and the fronds were cut into smaller sizes. The samples were sundried for two weeks for thorough drying before grinding, while the sawdust, which is a wood residue, was collected and bagged in polythene sacks as the logs were being processed in the sawmill. After the raw materials have been thoroughly sun dried, they were grinded into fine particles and sieved. The raw materials for the production of the briquettes were then mixed in the ratio as shown in Table 1.

**Table 1 Mixing ratio of the raw material**

| Raw materials | Sample A | Sample B | Sample C |
|---|---|---|---|
| Sawdust | 50 | 40 | 35 |
| Palm fronds | 25 | 30 | 35 |
| Banana peels | 15 | 20 | 20 |
| Starch | 10 | 10 | 10 |

2.3.2 Compression of raw materials

The next process involved pouring the appropriate mixture of raw materials into the hydraulic briquetting machine, and densifying the raw materials into a compressed and solid form.

2.3.3 Drying of briquette produced

The compressed briquette is then left to dry for a day to remove any remaining moisture and strengthen their structure.

**2.4 Characterization of briquettes produced**

2.4.1 Determination of density

The height of the briquette was measured using a vernier caliper and recorded. The diameter was measured from the top using the vernier caliper. The volume was calculated by the mathematical relationship $V = \pi r^2 h$. The mass was weighed using a tripod beam balance and was recorded. The density was calculated as;

$$\text{Density} = \frac{mass}{volume} \tag{5}$$

2.4.2 Determination of ignition time

Ignition time is the time taken for a flame to raise the briquette to its ignition point. The briquette samples were ignited at the edge of their base with a lighter adjusted to give a steady light. The time required for the flame to ignite the briquette was recorded as the ignition time using a stopwatch.

2.4.3 Determination of burning time.

After the briquette had been ignited, the stopwatch was left to keep taking time. The briquette sample was left to keep burning and the stopwatch keeps recording until the time the sample turns into ashes completely (Baileys and Blankenhorn, 1982).

2.4.4 Determination of moisture content

The moisture content is the amount of liquid (water) contained in the briquette after drying. The moisture content was determined using ASTM Standard E 711 – 87 (2004). Primary oven-drying method was used to determine the moisture content because it has the highest accuracy and degree of precision. During the analysis, a portion of each of the samples of the briquette was weighed out into an aluminum pan. The samples were placed in a tray dryer for 1 hour at 105°C. The moisture content was determined using the formula:

$$\% \text{ moisture} = \frac{w_o - w}{w} x100 \quad (6)$$

Where,

$w_o$ = initial mass of briquette before drying (kg);

$w$ = final mass of briquette after drying (kg).

2.4.5 Determination of the volatile matter in the samples

Volatile matter given off by a material as gas or vapor was determined by definite prescribed methods. In order to determine the percentage of volatile matter, 20 g of briquettes were kept in the furnace at a temperature of 550°C for 10 minutes (just before the materials turn black i.e before it ashes) and weighed after cooling. The percentage of volatile matter was expressed as the percentage of loss in weight to the oven dried weight of the original sample (Baileys and Blankenhorn, 1982).

Volatile matter = weight of residual dry sample– weight of dry sample after heating

$$\% \text{ Volatile matter} = \frac{w_i - w_f}{w_i} x100 \quad (7)$$

$W_i$ = weight of oven dried sample, N;

$W_f$ = weight of dried sample after 10 minutes in furnace at 550°C, N.

2.4.6 Determination of the ash content of samples.

Ash content predicts the purity and gives an indication about the quality of wood sawdust. Thus, the ash content of wood is the residue that remains after the wood material is burnt and such residue is referred as the non-combustible residue. The residual samples from the volatile content were weighed and allowed to burn into ashes inside the crucibles. It was allowed to cool. Afterwards the crucibles and their contents were reweighed, and the new weight was recorded. The percentage ash content was calculated according to Baileys and Blankenhorn (1982).

$$\% \text{ Ash content} = \frac{final\ weight\ of\ sample}{initial\ weight\ of\ sample} \times 100 \quad (8)$$

2.4.7 Determination of the fixed carbon content

Fixed carbon is the solid combustible residue that is present in a biomass sample after the percentages of ash content and volatile matter have been determined. It represents the quantity of carbon that can be burnt by a primary current of air drawn through the hotbed of a fuel (Inegbedion and Ikpoza, 2022.). The fixed carbon content of the samples was calculated using the following relation:

% Fixed carbon = 100 – (% Moisture content + % Volatile matter + % Ash content)

2.4.8 Determination of the calorific value

The high heating value is the amount of heat produced by the complete combustion of a unit quantity of fuel. This was calculated using the formula (Kwaghger et al. 2017).

Heating value = 2.326(147.6C + 144V) MJ $Kg^{-1}$ (9)

Where,

$C$ is the percentage fixed carbon;

$V$ is the percentage volatile matter (Bailey and Blankenhorn, 1982).

## 3 Results and discussion

### 3.1 Result of the designed and fabricated briquetting machine

From the design calculations, the force required to compress nine briquettes is 5,195.4 N, the thickness of the cylinder walls (t) ≥ 0.0095mm and the maximum shear stress in the cylinder is 0.44 MPa. Finally, the dimensions of the mould is 330 × 330 mm. The frame of the briquetting machine was constructed to house the moulds, base plates, hydraulic jack and pistons. Mild steel was used for constructing the frame as shown in Figure 1. The briquetting machine has nine moulds in total.

Figure 1 Fabricated briquetting machine

### 3.2 Results of the briquette produced

The briquettes were produced by mixing the raw materials in varying ratios and compressing them by using the hydraulic briquetting machine. Figure 2 shows the image of the briquette produced.

Figure 2 Briquettes produced.

### 3.3 Results of characterized briquettes

The results of the characterized briquette are as shown in Table 2.

**Table 2 Result of characterized briquette**

| Sample | Sample A | Sample B | Sample C |
|---|---|---|---|
| Density (g cm$^{-3}$) | 0.15 | 0.146 | 0.152 |
| Ignition time (sec) | 35 | 39 | 40 |
| Burning time (min) | 36 | 31 | 32 |
| Moisture content (%) | 13.3 | 10 | 16.6 |
| Volatile matter (%) | 46.1 | 62.9 | 68 |
| Ash content (%) | 14.2 | 20 | 25 |
| Fixed carbon content (%) | 26.4 | 7.1 | 2.4 |
| Calorific value (kJ kg$^{-1}$) | 24504.5 | 23505.5 | 23600.2 |

The Density of the briquettes obtained from the analysis in the production of the briquettes in varying mixing ratios include 0.15 g cm$^{-3}$ for sample A, 0.146 g cm$^{-3}$ for sample B and 0.152 g cm$^{-3}$ for sample C. According to Alzate Acevedo et al. (2021) higher densities generally led to improved combustion efficiency and reduced emissions. However, excessively high densities could hinder air flow and negatively impact combustion.

From the results of the analysis, the ignition time of the samples is 35 seconds for sample A, 39 seconds for sample B and 40 seconds for sample C. Sample A has the same ignition time as what was reported by Miller and Takase (2023) for briquettes made from sawdust alone, while sample B and C have higher ignition time than what was reported. This could, however, be attributed to the reduced concentration of sawdust in sample B and C. Farooq et al. (2021) reported an ignition time of 37 seconds for briquettes made from banana peels alone and Oladeji (2015) reported an ignition time of 32 seconds for briquettes made from palm fronds alone.

From the results obtained from the analysis, the burning time of sample A is 36 minutes, sample B had 31 minutes, and sample C had 32 minutes. This is lower than what was reported by Farooq et al. (2021) for briquettes made from Sawdust alone which is 40 minutes. This could be attributed to the mineral constituents of the banana peels and palm fronds added to the sawdust to make the briquettes.

The results from the analysis showed that the mixture of raw materials in varying ratios provided different percentages of moisture content with sample A having 13.3%, sample B having 10% and sample C with 16.6%. The moisture contents from the combination of sawdust, banana peels and palm fronds for the three samples is slightly higher than what was reported by Farooq et al. (2021) in the production of briquettes from sawdust alone which is 10%, however it is important to note that sample B has the same moisture content as what was reported by Farooq et al. (2021). The moisture content of briquettes produced from banana peels alone according to Miller and Takase (2023) is 8.3%, while the moisture content of briquettes produced from palm fronds alone as reported by Oladeji (2015) is 7.6%. Low moisture content is very important in briquettes as it aids in the storage and transportation of the briquettes.

The volatile matter, obtained from the analysis for the production of briquettes in various mixing ratios, includes 46.1% for sample A, 62.9% for sample B and, 68% for sample C. The volatile matter of the three samples is lower than what was reported by Farooq et al. (2021) for briquettes produced from sawdust alone which is 85%, this can be attributed to the chemical properties of banana peels and palm fronds. Similarly, Miller and Takase (2023) reported a volatile matter of 75.1% for briquettes made from banana peels alone, while a volatile matter of 66.1% was reported by Oladeji (2015) for briquettes made from palm fronds alone.

According to the results from the analysis, the samples have an ash content ranging from 14.2% to 25% which is significantly higher than what was reported by Farooq et al. (2021) for briquettes made from sawdust alone, this can be attributed to the addition of palm fronds, banana peels and starch. Miller and Takase (2023) reported an ash content of 2.63% for briquettes made from banana peels alone and Oladeji (2015) reported an ash content of 6.32% for briquettes made from palm fronds alone. The high ash content of the samples of the briquettes made from sawdust, banana peels and palm fronds can be attributed to the individual properties and mineral contents of the substrates. The higher the ash content the lower the calorific value of the substrates.

The results from the analysis showed that sample A had the highest fixed carbon content of 26.4%, Sample B had 7.1% and Sample C had 2.4%. Farooq et al. (2021) reported a fixed carbon content of 12% for briquettes made from sawdust alone, this happens to be less than the fixed carbon content of sample A and greater than both sample B and C. This can be attributed to the low volatile matter in sample A because a low volatile matter would translate to a higher fixed carbon content. Oladeji (2015) reported a fixed carbon content of 25.68% for briquettes made from palm fronds alone, while Miller and Takase (2023) reported a fixed carbon content of 13.97% for briquettes made from banana peels alone. A high fixed carbon content is essential for a higher calorific value in briquettes. Higher fixed carbon generally increases the calorific value, since carbon oxidation releases substantial heat. Fixed carbon is the slow-burning "char" aspect of biomass. More fixed carbon means higher and longer-lasting energy output, higher combustion temperatures, and more efficient char combustion.

The results from the analyses showed a calorific value of 24.5 MJ kg$^{-1}$ for sample A, 23.5 MJ kg$^{-1}$ for sample B and 23.6 MJ kg$^{-1}$ for sample C. Sample A had the highest calorific value. This further supports the fact that briquettes with a high fixed carbon content have a higher calorific value. Farooq et al. (2021) reported a calorific value 32.3 MJ kg$^{-1}$ for briquettes made from sawdust alone which happens to be higher than the results from the three samples of briquettes made from the combination of sawdust, banana peels and palm fronds and this can be attributed to the ash content of the samples which is higher compared to briquettes made from sawdust alone. Oladeji (2015) reported a calorific value of 17.48 MJ kg$^{-1}$ for briquettes made from palm fronds alone. This shows that the combination of sawdust, palm fronds and banana peels are an efficient source of energy for domestic and industrial usage.

Production of briquettes from mixed biomass sources faces challenges related to raw material variability, scale-up limitations, and binder requirements. These include inconsistent feedstock quality, difficulty in optimizing the briquetting process for diverse materials, and the need for binders, which can add to production costs. Fluctuating moisture levels in biomass can affect the briquetting process and the final briquette's durability and heating value. High ash content can reduce the calorific value of the briquettes and increase the potential for slagging and fouling in combustion. Low lignin content in some biomass can make it difficult to bind the material without the use of binders (Wu et al., 2025).

Handling and processing large volumes of diverse biomass materials can be complex and require specialized equipment. Finding the right binder and its optimal concentration for different biomass mixtures can be challenging and costly. Optimizing the briquetting process (e.g., pressure, temperature, and residence time) for various biomass combinations is crucial for consistent briquette quality. Industrial-scale briquetting equipment may need to be adapted to handle the specific properties of biomass briquettes (Nikiema et al., 2022).

## 4 Conclusion

The hydraulic briquetting machine was designed and fabricated from parts made from mild steel. The machine produces and ejects the briquettes effectively, the machine can produce nine briquettes at once. The briquettes were produced from sawdust, banana peels and palm fronds by using the hydraulic briquetting machine. From the results obtained during the analysis it was found that sawdust, banana peels and palm fronds are an efficient source of biomass for briquettes production. However, the most viable mixture for the production of sawdust, palm frond and banana peels briquette of different ratios based on high performance from the analyses was 50% sawdust, 25% palm frond and 15% banana peels due to its low ash content and high calorific value amidst many other properties.

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