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Thermal and Physical Properties of Briquette Fuels from Coconut Shells and Cocoa Shells

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ABSTRACT. This study explores the production and characterization of biomass briquettes from coconut and cocoa shells, which are abundant agricultural residues in tropical regions. The motivation behind this research was to investigate the feasibility of utilizing these biomass waste streams for fuel through briquetting, promoting renewable energy applications, and waste management. Briquettes were prepared using different ratios of coconut shells, cocoa shells, and starch as a binder. The mixture was moulded into uniform cylinders and dried to remove moisture and solidify the binder. Thermal properties, such as gross calorific values ranging from 15.92 to 18.30 MJ/kg, and physical properties, including proximate composition, bulk density, and shatter resistance, were assessed. Testing revealed volatile matter ranging from 68.20% to 77.36%, ash content from 9.85% to 13.36%, bulk densities of 0.31 to 0.59 g/cm^3, and shatter resistance values from 55.55% to 97.53%. Results showed that the briquettes with a 50:50 ratio had the highest calorific value and density, while the 100% coconut shell briquettes exhibited the highest strength. Overall, the biomass briquettes demonstrated thermal and physical qualities suitable for use as renewable solid fuels, with composition significantly influencing their characteristics. Further optimization of formulations tailored to specific applications could enhance the utilization of these agricultural residues.

Keywords: Briquettes, Cocoa shells, Coconut shells, Proximate analysis

INTRODUCTION

Biomass, which encompasses organic matter derived from plants such as forest wood, crops, seaweed, and various forms of waste, holds significant potential as a renewable energy source(Saidur et al., 2011). The utilization of non-food plant materials for energy production has gained attention due to their abundance and the opportunity to convert waste into a valuable energy resource (Tursi, 2019). This renewable resource can be harnessed through direct combustion or by transforming biomass into biofuels, offering a versatile and sustainable alternative to traditional fossil fuels(Ferronato et al., 2022). Biomass, characterized as a carbon-based material, consists of a complex mixture of organic molecules containing elements such as hydrogen, oxygen, nitrogen, and trace amounts of alkali, alkaline earth, and heavy metals (Khan et al., 2009). Among the different biomass sources, wood remains the primary and most widely used biomass energy source, comprising forest residues, yard clippings, wood chips, and municipal solid waste (Bajwa et al., 2018; Mencarelli et al., 2022). However, a diverse range of plant species, including eucalyptus, palm trees, switchgrass, hemp, corn, poplar, willow, sugarcane, and bamboo, can be cultivated specifically for industrial biomass purposes (Bassam, 2013).

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Biomass residues commonly used for briquette manufacturing include crop-based waste such as grain shells, husks, and straw from crops like paddy, wheat, coconut, and areca nut. Additionally, municipal solid waste like wood chips, paper waste, and sawdust can be utilized for this purpose (Dinesha et al., 2019). However, in this particular study, coconut and cocoa shells were specifically chosen as briquette materials due to their combustible properties, as indicated by the findings of (Marcelino et al., 2023) and (Spilacek et al., 2014). By utilizing these agricultural residues, not only can we promote renewable energy applications, but we can also effectively manage waste in tropical regions.

This study aimed to explore the production and characterization of biomass briquettes from coconut shells and cocoa shells, assessing their potential as renewable solid fuels by considering thermal and physical properties and providing insights for further optimization in specific applications. By examining the characteristics and performance of briquettes, valuable insights can be gained regarding their feasibility and applicability in various energy production systems (Mwampamba et al., 2013). The current study contributes to the growing body of research on biomass utilization and its potential as a renewable energy source (Bot et al., 2022). Understanding the properties and behaviour of briquettes derived from coconut and cocoa shells can expand the range of biomass materials used for energy production. Furthermore, investigating the thermal and physical properties of the biomass briquettes will provide valuable information for optimizing their production process and assessing their suitability for specific energy applications (Obi et al., 2022). Ultimately, this research aims to contribute to the development of sustainable and environmentally friendly energy solutions by exploring the potential of biomass briquettes as a renewable energy source.

METHODOLOGY

Materials

The coconut and cocoa shells were collected, washed to eliminate any unwanted materials, and sun-dried for approximately three days. Subsequently, both types of shells were crushed using a crusher (Daiko Seiki, Japan) to achieve an approximate particle size of 2 mm. The resulting particles were then collected using a sieve shaker.

To cast the briquettes, a binder was prepared by mixing starch powder with boiled water in a 1:2 ratio. The ground coconut shells and cocoa shells were combined with the binder in three different proportions: 100:0, 50:50, and 0:100 (coconut shells to cocoa shells). The mixture was then pressed into moulds, forming uniformly shaped cylinders with a diameter of 22 mm and a length of 50 mm. Subsequently, they were subjected to drying in a convection oven at 70°C for three days to remove excess moisture and allow the binder to solidify.

Thermal Properties

Gross Calorific Value: The gross calorific value was determined using an adiabatic bomb calorimeter. Approximately 0.5 g of the sample briquette was placed in the sample holder and analyzed using the Ika

Works/C5000 Control bomb calorimeter.

Physical Properties

Proximate Analysis

Percentage Volatile Matter (PVM): To determine the percentage of volatile matter in the briquettes, 2 g of the sample was placed in a crucible and baked until it reached a constant weight. The crucible with the sample was then placed in a furnace at 550 °C for 10 minutes, allowed to cool in a desiccator, and then weighed. The PVM was calculated using the following equation:

$$\mathrm{PVM} = \frac{\mathrm{A-B}}{\mathrm{A}} \times 100 \tag{1}$$

Where; A is the weight of the oven-dried sample (g)

B is the weight of the sample after 10 min in the furnace at 550°C (g)

Percentage Ash Content (PAC): To determine the percentage of ash content in the briquettes, 2 g of the sample was heated in a furnace for 4 hours at 550 °C. After cooling in a desiccator, the sample was weighed to determine the weight of ash (C). The PAC was calculated using the following equation:

$$\mathrm{PAC} = \frac{\mathrm{C}}{\mathrm{A}} \times 100 \tag{2}$$

Bulk Density: To determine the bulk density of the briquettes, an empty cylindrical container with a volume of 100 ml was weighed and filled with the briquette sample. The container was then weighed again, along with the sample. The bulk density was calculated by dividing the mass of the material by the volume of the container using the following formula:

$$\text{Bulk density} = \frac{\text{Mass of briquette sample (g)}}{\text{Volume of measuring cylinder (cm}^3\text{)}} \tag{3}$$

Shatter Resistance: To determine the shatter resistance of the briquettes, the sample was weighed and dropped from a height of one meter onto a concrete floor ten times. The sample was then weighed again, and the percentage loss of mass was calculated using the formula suggested by Madhava et al. (2012):

$$\text{Weight loss}(\%) = \frac{\mathrm{W_1 - W_2}}{\mathrm{W_1}} \times 100 \tag{4}$$

$$\text{Shatter resistance}(\%) = 100 - \text{Weight loss}(\%) \tag{5}$$

Where; W_1 = weight of briquette before shattering, g

W_2 = weight of briquette after shattering, g

RESULTS AND DISCUSSION

Thermal Properties

In Table 1, three different types of briquettes were analyzed for their gross calorific values: coconut shell briquettes, cocoa shell briquettes, and mixed briquettes containing an equal percentage of coconut and cocoa shells. The briquette with the highest energy content was coconut shell briquettes at 18.30 MJ/kg, followed by mixed briquettes at 17.40 MJ/kg. The lowest calorific value was observed for cocoa shell briquettes at 15.92 MJ/kg. Interestingly, the coconut shell and mixed briquettes fall within the typical range of 17-21 MJ/kg reported by Zakari et al. (2013) for good-quality biomass briquettes. Good biomass briquettes are characterized by high energy content and sustainable sourcing (Oladeji, 2015). On the other hand, cocoa shell briquette had a calorific value below the acceptable minimum, reflecting poorer energy properties. The higher carbon and volatile matter percentages, among other factors, contribute to the higher energy densities of coconut shells than cocoa shells (Kumar et al., 2010; Suryaningsih et al., 2017). Overall, blend ratios and biomass selection influence the gross calorific values obtained for different briquette formulations. Higher energy densities point to more favourable combustion characteristics and fuel qualities. Further analysis of fuel properties can provide valuable insights for developing optimized solid biofuel designs.

Table 1. Gross calorific value of briquettes of different compositions.

Composition (wt.%)	Gross Calorific Value (MJ/kg)
Coconut (100)	18.30
Cocoa (100)	15.92
Mix (50:50)	17.40

Physical Properties

Proximate Analysis: Figure 1 illustrates the composition analysis of briquettes with different compositions, focusing on the percentage of volatile matter, fixed carbon, ash content, and moisture. The percentage of volatile matter (PVM) showed slight variations among the three compositions. Coconut shell briquettes exhibited the highest value at 77.36%, while cocoa shell briquettes and mixed briquettes recorded values of 68.20% and 74.37%, respectively. Volatile matter is an important factor as it represents the gaseous fuels present in the briquettes and contributes to flame length and ignition ease, as highlighted by Suryaningsih et al. (2017). It encompasses substances like methane, hydrocarbons, hydrogen, carbon monoxide, and incombustible gases such as carbon dioxide and nitrogen. Regarding ash content (PAC), there were significant differences between coconut shell briquettes and cocoa shell briquettes, with respective values of 13.36% and 9.85%, while mixed briquettes exhibited a PAC of 12.19%, which is considered desirable. Ideally, biomass fuels contain less than 10% ash to maximize the portion of combustible constituents. However, ash values exceeding 15% are unfavourable as they have been shown to induce significant slagging and clinkering problems during combustion due to the fusion of mineral residues (Kpalo et al., 2020).

In terms of fixed carbon (PFC), the three briquette compositions showed similar percentages. Coconut shell briquettes had 13.22% PFC, while cocoa shell briquettes and mixed briquettes had values of 14.32% and 12.78%, respectively. This indicates that a high proportion of solid fuel remains in the furnace after the volatile matter has been distilled. Fixed carbon mainly consists of carbon but may also contain small amounts of hydrogen, oxygen, sulphur, and nitrogen that were not released with the gases. The high PFC values in all three briquette compositions suggest a higher gross calorific value (Millogo et al., 2022).

When examining the moisture content, cocoa shell briquettes displayed the highest value at 7.63%, while coconut shell briquettes and mixed briquettes had moisture contents of 6.20% and 5.33%, respectively. The higher moisture content in cocoa shell briquettes can be attributed to the cocoa shell's absorbent structure, which retains some moisture, as noted by Huang (2014). Optimal moisture content typically falls within the range of 10-18%, as lower or higher levels may result in briquettes breaking apart. Relatively low moisture content in all three briquette types can influence their strength. Moisture can displace combustible matter, reducing the heat content of the briquette and leading to heat loss through evaporation and superheating of vapour. However, moisture plays a role in binding fines and facilitating radiating heat transfer.

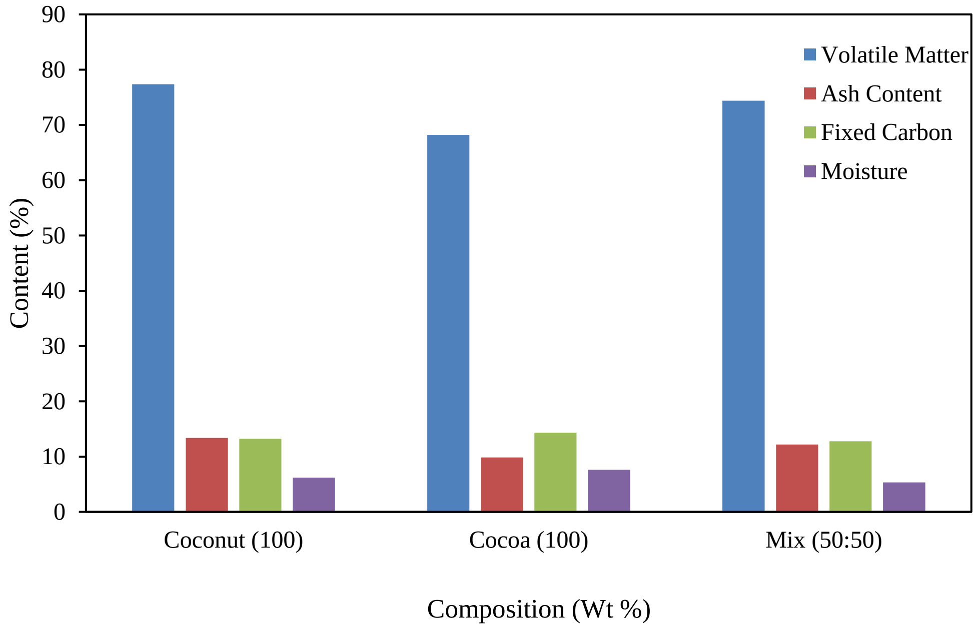

Figure 1. Proximate analysis and moisture content of briquettes at different compositions.

Bulk Density: According to Figure 2, coconut shells briquette had the maximum bulk density of 0.59 g/cm^3. High bulk density is desirable in briquettes because it can hold more combustible matter in its packing, providing heat that lasts longer (Tesfaye et al., 2022). Cocoa shells briquette had the lowest bulk density of 0.31 g/cm^3, while mixed briquette had a density of 0.40 g/cm^3. The density of the mixed briquette was mostly contributed by the coconut shells.

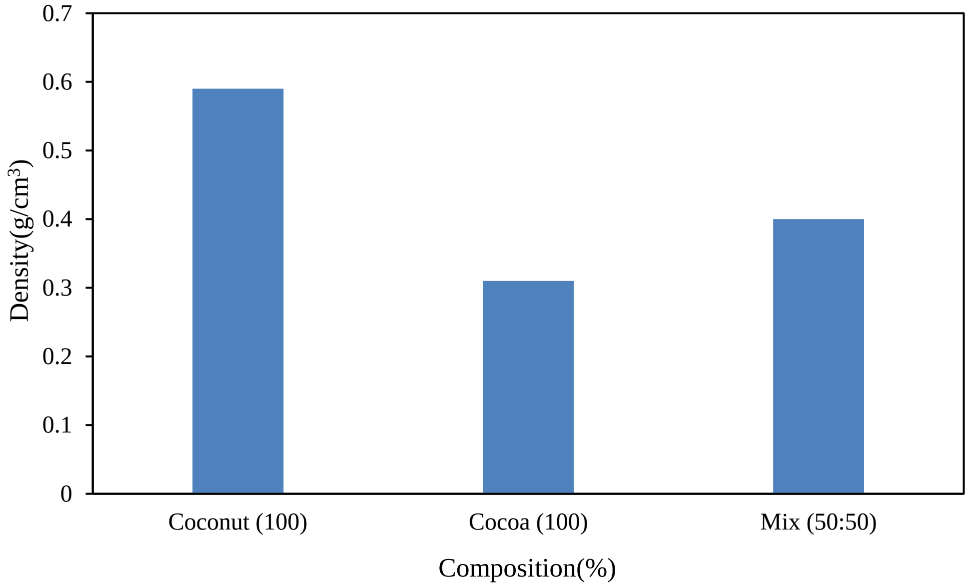

Figure 2. Bulk density of briquette at different compositions.

Shatter Resistance: Figure 3 shows that the cocoa shell briquette exhibited the highest shatter resistance of 97.53%, which is desirable, as briquettes with high shatter resistance have greater shock and impact resistance, as reported by Birwatkar et al. (2014). In contrast, the coconut shell briquette demonstrated the lowest shatter resistance at 55.55%, while the mixed briquette achieved an intermediate level of 78.60%. The higher shatter resistance of the cocoa shell briquette may be attributed to the closer, tighter packing of the medium-hardness cocoa shell particles.

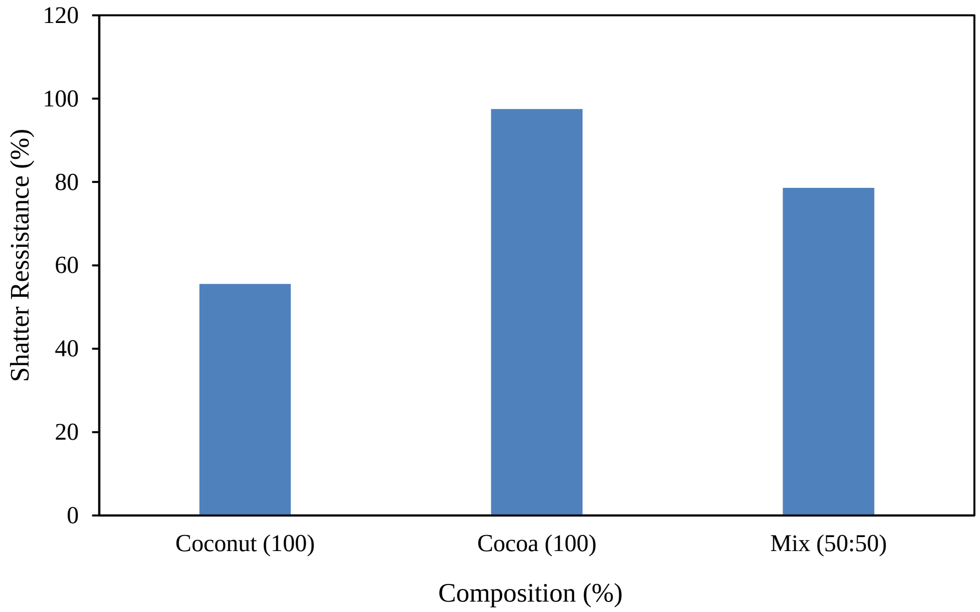

Figure 3. Shatter resistance of briquette at different compositions.

In comparison, the coconut shell particles were harder, resulting in lower bonding and shatter resistance in the coconut shell briquette. Studies have established that quality briquettes necessitate ≥90% shatter resistance to withstand logistical handling, as referenced in the review by Kaliyan and Morey (2009). At about 79%, the mixed ratio briquettes fell below this optimal threshold, indicating extra care would be required when transporting and using these briquettes due to their compromised durability against mechanical stresses compared to cocoa shell briquettes.

CONCLUSION

The results demonstrate that both coconut shells and cocoa shells have the potential to form good-quality briquettes due to their combustible nature. Thermal analysis of briquettes made from coconut shells and cocoa shells showed that both materials have the potential to form good-quality briquettes. The high heating value of the briquettes ranged from 15.92 to 18.30 MJ/kg, with density varying from 0.40 to 0.59 kg/m^3 and crush resistance ranging from 55.55% to 97.53%. Proximate analysis revealed that the fixed carbon content of the briquettes was between 12.78 and 14.32%, volatile matter was between 77.36 and 68.20%, ash content was between 9.85 and 13.36%, and moisture content was between 5.33 and 7.63%. Ultimate analysis showed that the briquettes contained carbon in the range of 56.95 to 62.70 %, hydrogen from 6.12 to 6.90%, and nitrogen from 0.55 to 0.74%. However, briquettes made entirely from coconut shells exhibited the most desirable properties. They had the highest heating value (18.30 MJ/kg), highest carbon content (62.70%), and highest bulk density (0.59 g/cm^3). The mixed ratio briquettes had insufficient shatter resistance at 79%, requiring more careful transport and use than cocoa shell briquettes. In summary, coconut shell briquettes displayed the best performance among the three types studied.

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AUTHOR CONTRIBUTIONS

Sabirin Mustafa conducted the research and drafted the manuscript, while Shariff Ibrahim reviewed and edited it.

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DATA AVAILABILITY

Not applicable.

COMPETING INTEREST

The authors declare that there are no competing interests.

COMPLIANCE WITH ETHICAL STANDARDS

Not applicable.

SUPPLEMENTARY MATERIAL

Not applicable.

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