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COMBUSTION, PHYSICAL AND MECHANICAL CHARACTERISTICS OF BRIQUETTES PRODUCED FROM COCONUT RESIDUES BY THREE COMPANIES IN GHANA

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Abstract:
Converting biomass into a product that can be utilised efficiently for energy production is vital for its proper use. During briquetting, agricultural waste is turned into a product that is easily transportable, easy to handle, and easy to handle, as well as solid blocks that are more beneficial than raw biomass. Because of their makeup and natural differences, it is essential to be aware of the ideal techniques that must be adopted for more durable and lasting fuel from individual biomass compacted into briquettes. The physical, mechanical, and combustion characteristics of the bio-briquettes samples were examined in this study. The moisture content, volatile matter, fixed carbon, density, ash content, calorific value, and compressive strength were analysed with existing standards and compared with the values from the other studies. Results revealed that the briquettes samples have a mean value of moisture content (7.02 - 8.76%), volatile matter (46.11- 61:03%), fixed carbon (41.64 - 26.26%), briquette density (1.16 -1.33g/cm³) ash content (55 - 63.8%), calorific value (22.35 - 21.45MJ/kg) and compressive strength in cleft (0.43-1.25N/mm²)-suitable for domestic use, packaging, storage and transportation. This study has revealed that durable and quality briquettes can be achieved with better combustion, physical and mechanical properties can be produced with coconut husk and shell with cassava starch as a binder and can serve as another way of accessing energy and controlling waste.

***Key words**: biomass; residue; mechanical property and combustion.*

INTRODUCTION

Coconut is an all-year-round perennial fruit that thrives well on sandy soils and mainly grows well on islands and coastal areas in the tropics and rainforest climate, especially along the coastline zones where it enjoys the sun irradiation as well as water (UNCTAD 2016). Several million tons of coconut are cultivated yearly worldwide, mainly in Asia, Latin America and Africa. As of 2018, the global cultivation of coconut had risen to 250-300 million tonnes (Rahamat et al. 2019). The coconut shell does not readily decompose as the husk does, and it sometimes becomes a nuisance in the environment. Agricultural waste, including coconut husk and the shell, has good fuel properties and, therefore, can be converted into a fuel source for domestic purposes (Aremu 2019).

The source of energy is vital to human lives, and it makes a very distinct impact in diverse ways (Fikremariam et al. 2020). Nonrenewable energy sources such as fossil fuel, coal, and kerosene usage cause a great deal of harm to human lives in the form of the emission of poisonous gases such as (GHG), CO2, SOx and NOx (Sisey et al. 2020). Lately, there has been a paradigm shift towards the use of environmentally healthier, sustainable energy sources, which have a less negative impact on the user and

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the environment, particularly on women and children who are left with chronic illnesses (Rees 2016). Hailu (2021) opined that the effect of greenhouse gas emissions highly affects developing countries worldwide.

The act of converting agro waste into a highly densified product, a high-densified solid material that can serve as a fuel source, is called briquetting. Using agricultural waste (biomass) in agricultural waste (biomass) contributes immensely to the energy mix. The briquette process increases the properties of the materials, such as density, heating value, and water content. Briquettes are easier to handle, transport and store than biomass use in their native state (Radenahmad et al. 2018). It contributes immensely to the sustainable and efficient utilisation of agrowaste (Pazmino-Hernandez et al. 2017). Quality briquette production is greatly affected by some activities before, during or after production (Mitchual et al. 2013). Before production activities include the properties of the raw material, such as the water content and the particle size of the milled material (Eissa et al. 2013). Specialised conditions of the compaction operation (temperature, pressing application, pressure) and the form (shape and size) of the briquette are some activities that affect the briquette quality during production. At the same time, after-activity concerns how they are handled, stored and moved Brunerová et al. (2018).

In Ghana, the overwhelming quantity of coconut waste produced daily and its inappropriate management, coupled with its negative effect on the environment, has resulted in the establishment of recycling companies, where the waste is converted into briquettes. Several parameters, including density, resistance to gravity drop, water absorption resistance, radial compression strength and calorific value, determine biomass briquettes' quality. However, durability is the primary parameter characterising the quality of a produced briquette (Brunerova et al. 2016). This study, therefore, reviews biomass briquettes made from coconut waste with cassava starch as a binder from three companies. The objective is to compare their physical, combustion, and mechanical properties with existing standards, such as the American Standards for Testing Materials (ASTM) and the International Standards Organization (ISO), and some recommended standards by other researchers.

MATERIALS AND METHODS

Material acquisition and preparation

The purposive technique was adopted for the sample selection. So many production companies use another type of biomass for their briquette production. Still, for this study, they were selected purposefully based on factors such as the briquette age (not less than six weeks after production), the type of biomass (other than coconut husk and shell) and the type of binder (must be cassava starch) as indicated in Fig. 1. The briquette samples' combustion and physical and mechanical properties were assessed, and five replicates were run for each formulation. The multiple companies have been named AA, FF and ZZ for easy identification and complete confidentiality. The researcher had the opportunity to interact with managers of various companies to obtain brief knowledge concerning their production procedures. The raw materials are obtained in Ghana's Greater Accra and Eastern regions. Company AA collects coconut waste from Kyebi in the Kyebi municipal district of the Eastern region. In contrast, FF and ZZ collect the raw materials at Abossey-Okai in the Ablekuma central district and Dodowa in the Dangme West district of the Greater Accra region. They were all from coconut vendors who conveyed the company directly or to the dumping site. The companies used trucks to convey supplies and their wastes to the company directly or to the dumping site, and companies used trucks to transport to their various production sites. According to the information gathered, after the collection, the wastes are exposed to sun drying, which drying dries for 14 days. This period can change depending on the temperature, usually within two weeks (7-14 days). After drying, the wastes are sorted into groups comprising shell only, husk only, and then the shell and husk attached. The materials are then cleaned from foreign materials such as sand, metals, weeds, glass stones, and others.

Fig. 1.
a-c - Fresh and dry coconut shell and husk.

Biomass carbonization

The material (coconut husk and shell) was charred to increase its properties. During carbonization, the dried biomass wastes are packed into a conventional drum, which is locally manufactured with minimal equipment. A chimney attached to a metal lid is then used to cover the container to avoid the entrant of oxygen and serve as a channel for escaping smoke and gases. During the process, gases and liquids like smoke and tar are released. This is done at 400-440°C with a time range of 45 minutes to 1 hour depending on the quantity and group of material, according to the production managers of the three companies. The entrant of oxygen is completely disallowed to stop the burning and then allowed to cool to prevent ash formation.

After charring, the charcoal is milled into a powdered form through pulverization, which results in homogeneous powder (charcoal powder). A locally fabricated mill (hammer mill) grinds the charcoal into fine particles. A sieve is sometimes employed, depending on the particle sizes required.

Preparation of the binding material and densification

The cassava starch is prepared by mixing the powdered starch with water at a ratio of 1:8 1000g starch to 0.800 litres of water. Different types of press produce briquettes of different shapes and sizes. Fig. 2 shows the steps involved and the results of the various processes.

Fig. 2.
a-c - The briquette materials and process.

Briquette densification procedure

The briquettes are produced with different types of press, such as a manually operated hydraulic press, roller, screw press and others. The size and shape of the product depend on the type of press used. Mixing biomass and binder is either done manually with a shovel or with a mixer. The mixture is fed into the machine for densification, which involves compacting at an undisclosed pressure level. The produced briquettes are placed on a flat surface and left to sun dry for 20-25 days before packaging and distribution.

Characterization of the samples

The samples' percentage of Moisture content, Calorific value, Volatile matter, Ash content, Fixed carbon, and Compressive strength were determined.

M**oisture content** (MC): The percentage of Moisture content was determined using the ASTM D2444-16 method. The initial weight was recorded using a digital weighing scale. Before the weight was determined, the empty pan's weight was adjusted to zero (0.00kg) not to affect the samples' actual values. The samples were then put in an oven at (103 ± 2)°C for 24 hours. They were removed and allowed to cool for an hour before another weighing process as indicated in Fig. 3. The sample's Moisture content percentage was calculated using the formula by (Tembe et al. 2014).

$$\text{Moisture content}(\%)\ bs = \frac{M1-Mo}{Mo} \times 100$$

where: M1= Mass of the sample before drying (g) Mo=Oven-dry mass of the sample (g).

Fig. 3.
a-b - Oven drying of the sample.

Density of briquette: The bulk Density of the briquette was determined following the ASTM D7481-09 (2009). The sample weights were recorded with an electronic weighing balance, as well as the diameter and thickness. The height of the briquettes determined the volume and was recorded with a digital calliper. The volume was determined using a measuring can (Fig. 4). The Density was calculated by:

$$p = \frac{initial\ Mass\ of\ the\ materials}{Volume\ of\ cylinder}\left[\frac{g}{cm^3}\right]$$

Fig. 4.
a-b - Briquette volume determination.

Fixed carbon (FC) was determined using proximate analysis with ASTM D3175-15. The sum of moisture content (MC)%, volatile matter (VM)%, and ash content (AC) % was calculated. The following equation calculates the ash content (AC) %. The following equation was used to calculate the Fixed carbon content.

$$FC = 100\% - (MC + VM + AC)$$

Volatile matter determining: This test was conducted following the ASTM, D3175-18 method. The samples were dried in an oven at 110℃ for two hours to obtain a constant weight. They were then removed and allowed to cool. The weights were determined and recorded as oven-dry weight (w2). They were then put in a furnace and ignited for 8 minutes at 550℃. They were transferred to the desiccator to cool. The sample weights were recorded after cooling to obtain (w3). The percentage of volatile matter was calculated using the formula by (Awulu et al. 2015).

$$V.M.\% = \frac{W2-W1}{W2-W3} \times 100$$

W1 = weight of empty crucible, g; W2 = weight of crucible + sample, g; W3 = weight of crucible + sample after heating, g.

Ash content (AC): this was determined using the ASTM D3174-12 method (Fig. 5). The weight of the briquette samples obtained after the volatile matter was determined and recorded as (W5) and heated gradually in a muffle furnace at 550°C for 4 hours. After that, it is transferred into a desiccator cool. The weight was determined after cooling and recorded as (W4). The Ash content present was determined using the following equation (Awulu 2015).

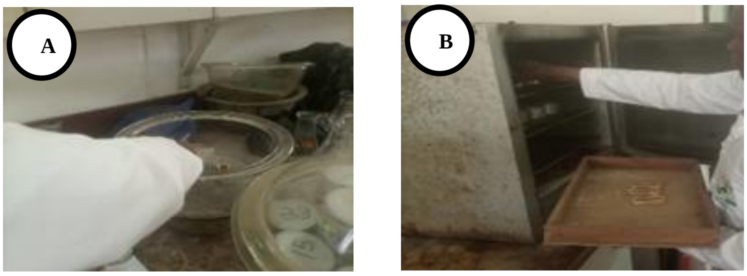

Fig. 5.
a-b - Samples being placed in the furnace.

$$\text{Ash content (\%)} = \frac{W5}{W4} \times 100$$

Calorific Value*:* This test was conducted per the ASTM, D5865-13, Standard Test Method. The sample was pulverised, and then one gram (1g) was placed in a sample holder (crucible) and transferred to a steel capsule from the bomb calorimeter, as indicated in Fig. 6. After this, one gram (1g) of the sample was transferred into a crucible using a pair of tweezers and then weighed on an analytical balance; it was then placed on the crucible support of the bomb. The two electrode rods were connected to the firing wire, touching the sample in the crucible. Distilled water measuring ten millilitres in quantity was poured into the oxygen bomb, then the sample was placed inside and covered. The oxygen bomb was filled with oxygen at a pressure range between 2.5-4.0 MPa for 12 seconds, after which the pressure valve was released. The calculation used the following equation (Adetogun et al. 2014).

$$HV = (FC\% + VM\%)\ \text{kJ/kg}$$

where: HV is the calorific value, FC is the fixed carbon content, and VM is the percentage of volatile matter.

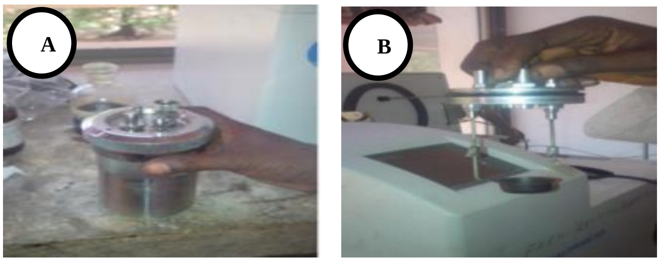

Fig. 6.
a-b - The calorimeter in use for the test.

Compressive strength (CS) was determined using an Instron Universal Strength testing machine with a load cell capacity of 100kN, per ASTM D3967-95a, as indicated in Fig. 7. The cross-head velocity was 0.305mm/min. In the compression testing machine, the sample was positioned horizontally. Until the briquette broke or cracked, a steady load of 0.305 mm/min was applied. The highest weight that resulted in the briquette breaking was noted. If the machine's hydraulic pump was not working, the load was applied manually by pulling on a lever, and the value was determined using an attached gauge. The compression tester provided the load, F, at which the briquette broke. The briquette's length, L, and diameter, D, were considered in the estimation of the cross-sectional geometry of the lateral plane. The equation was used to calculate the radial, lateral, rupture or compressive strength (CS) determined from the Equation:

$$CS = \frac{2F}{\pi DL}$$

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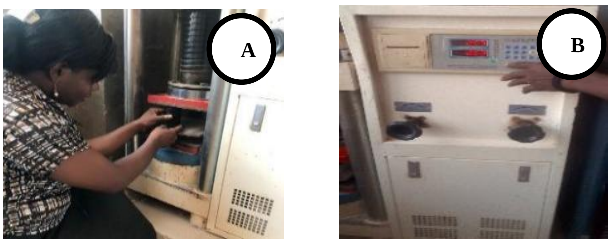

Fig. 7.
a-b - Positioning samples for compressive strength determination.

STATISTICAL DATA ANALYSIS

Data were examined using Bonferroni Post-hoc Tests in a fully randomised manner to see if the analysis of variance (ANOVA) assumptions were met. A significance threshold of P = 0:05 was chosen.

RESULTS AND DISCUSSION

Table 1 and Table 2 are presented.

Table 1

Mean Proximate Analysis of the Sample Briquettes

Residues	MC(*db*) *Mean ± SD*	Density (g/cm³) *Mean ± SD*	FC*(db)* *Mean ± SD*	VM(*db*) *Mean ± SD*	CV(MJ/kg) *Mean ± SD*	CS(N/mm²) *Mean ± SD*	AC(*db*)
AA	4.78-0.47b	1.21-0.02a	41.65-39 a	61.03-6.88a	21.45 -28.38a	1.25-0.43a	55 - 10.07a
FF	7.33-0.16a	1.33-0.04a	37.61-32.2b	57.61-5.58b	22.35 -18.24a	3.12-0.03 b	63.8 - 82.3b
ZZ	7.02-0.31a	1.16-0.0 a	26.26-20-8c	46.11-4.71c	21.46-54.34a	2.89 - 0.09 c	57.6 - 7.4a

Means within a column followed by the same letter a are not significantly different at 0.05 confidence interval. Fixed carbon; etc

Table 2

ANOVA Presentation of the Coconut Waste Briquette

Source	MC *Mean ± SD*	Density(g/cm³) *Mean ± SD*	FC *(db) Mean± SD)*	VM(*db*) *Mean ± SD*	CV(MJ/kg) *Mean ±SD*	AC(*db*) *Mean± SD*	CS (N/mm²) *Mean ±SD*
Ss	8.66	0.08	636.84	610.5	113873.2	204.4	682.19
df	2	2	2	2	2	2	2
Ms	4.33	0.04	34.84	305.25	56936.6	102.2	291.09
F-value	30.81	15.79	20.8	16.92	48.13	2.47	20.8
P-value'	≤0.005	<0.001	<0.001	≤0.005	≤0.005	.145	<0.005

PROXIMATE ANALYSIS OF THE BRIQUETTE SAMPLES

Proximate analysis of the samples indicates the percentage of the Moisture content (liquid state), Volatile matter (gaseous state), and Fixed carbon (solid state); the percentage of inorganic waste material (Ash); Calorific value for biomass energy user and the Compressive strength. Generally, due to the high combustion properties of the coconut waste, briquettes produced from the material often exhibit higher values. Table 3 presents the results obtained from this study, comparing some existing standards, such as the ASTM and ISO, and the recommendations from other researchers, as presented in Table 4. The desirability indices designed for the study are defined by three parameters (Low, Good, and High).

Moisture content (MC)

There was no discernible variation in the moisture content values between the samples with statistical analysis. (p > 0:05). The values obtained ranged between (8.76-7.0) %, as shown in Table 1. The values recorded in this study follow the values recorded by Arewa et al. (2016) and agree with the findings of Antwi-

Boasiako and Acheampong (2016), which suggested that highly dense briquettes are made from finely powdered ingredients and that the compaction process, the densification of fine materials releases extra water. The outcomes are consistent with the suggested moisture content tolerance range (8-15%) for biomass briquettes, as published by (Akpenpuun et al. 2020). The briquette sample ZZ exhibited the lowest moisture content compared to AA and FF, and This might be due to the relatively high binding material (starch present), good porosity, particle size and high bulk density of the briquette sample, as reported by (Saed et al. 2021).

Between the three samples, there was a significant variation in the briquette densities ($P<0.05$). Samples FF and AA had the highest and lowest mean densities, respectively, with 1.33 and 1.21g/cm³ and 1.16g/cm³. The results obtained align with the findings of Adenkule et al. (2022), who reported values between 0.92g/cm³ and 1.31g/cm³. The sample FF that recorded a greater density may have been associated with its moisture content and the amount of binder, compaction, and particle size utilised. Temperature and pressure are two of the most important variables affecting briquette, according to Jekayinfa et al. (2019) and Orisaleye et al. (2023).

The briquette densities significantly varied ($P \leq 0.05$) among the three samples. The highest mean density recorded was 1.33g/cm³ for sample FF, followed by AA with 1.21g/cm³ and AA with 1.21g/cm³; the lowest value of (1.16g/cm³) was recorded for Z. The obtained results are with Adenkule et al. (2022), who recorded values ranging from (0.92g/cm³-1.31g/cm³) sample FF recording higher density can be related to its moisture content and possibly the percentage of binder, compaction and particle size used. Jekayinfa et al. (2019) and Orisaleye et al. (2023) opined that pressure and temperature are among the most significant factors influencing briquette density. It is also known that the size of the particles can play an essential role in establishing the density of the briquettes.

Fixed carbon content (FC)

Regarding the proportion of fixed carbon contained in each sample, the analysis of variance showed a significant difference (p<0:05) between the samples. As indicated in Table 1, the sample AA had the greatest mean value, followed by FF with 40.3% and sample ZZ with 26.26%. These results concur with those of Kuma (2018), who discovered that the fixed carbon content of briquettes from biomass and coal dust varied from 27% to 61.76%. Achebe et al. (2018) define the fixed carbon of a fuel as the proportion of carbon accessible for combustion. Sample AA has the largest fixed carbon concentration, which is explained by its homogeneity and strong bonding.

Volatile matter (VM)

The proportion of volatile matter was an acceptable high percentage in this investigation. According to the ANOVA, the three samples' mean volatile matter values differ significantly (p<001). Table 1 displays the results of the proximal analysis. As can be seen from the table, sample AA briquettes contained the most volatile matter (61.03%), followed by FF and ZZ briquettes (57.61 and 46.11%, respectively). A similar outcome was attained by (Lawal et al. 2019) as they recorded 74.6% volatile matter.About fixed carbon, AA had the greatest value (49.65%), followed by FF (37.61%) and ZZ briquette (26.26%).This agrees with Kuma's (2018) findings of fixed carbon between 27% to 61.76%. The high value by sample AA can be attributed to good bonding and uniformity in the particle size, which resulted in the high density recorded.

Ash content (AC)

The nonflammable component derived from biomass is ash, and a high ash content means that less volatile material was used in the amount of fuel used in this investigation, as indicated by the statistical analysis (Table 1). The sample with the highest mean ash concentration was AA, which recorded a high value of 63.8%, followed by ZZ at 57% and FF at 55%. These results are consistent with those of Pranowo et al. (2021), who reported a high ash content of 68% and stated that the high ash content was caused by the materials used. Maninder et al. (2012) also suggested that ash content be high or low depending on the type of biomass waste and briquette burning technique. According to Aboagye (2017), the binder levels affect the ash content of the briquettes. When using the shell, more binder is required for better bonding. Therefore, the high ash content recorded can be attributed to a high binder ratio. The coconut husk naturally produces high ash content because of the high lignin present. Again, impurities might have found themselves attached to the coconut residue during production since the cleaning of the materials is done manually, though production is on a large scale.

Calorific value (CV)

Calorific value is the standard measure of the energy content of the fuel (Ikelle et al. 2014). The mean calorific value of briquettes produced from biomass wastes and binders significantly varied (p <0.05) among each sample, as shown in (Table 1). The highest mean value was recorded in sample FF (22.35MJ/kg),

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followed by sample AA (21.46 MJ/kg), with the lowest mean being recorded in sample ZZ (21.45MJ/kg). The calorific values obtained from this study are per the findings of Dalimunthe et al. (2020), which noted that coconut shell coal could have a high calorific value of (24.82MJ/kg). These results can be related to the low moisture content, high-density levels and possibly the percentage of binder (starch). Calorific values depend on the biomass type and the compactness level (Bianca et al. 2014). In this study, Arewa et al. (2016) recorded lower moisture content values and compared with the recommended moisture content of 8-15% (Akpenpuun et al. 2020).

Compressive strength (CS)

Values for the Compressive strength indicated a significant difference among all the samples with ($p<0.05$). The highest mean value recorded was 3.12N/mm² for briquette FF, followed by ZZ with 2.89N/mm² and the least value of 1.25N/mm² for AA. These values are per the result of Orisaleye et al. (2024), ranging from 3.00N/mm² to 1.50N/mm². Again, it is in line with the suggestion from Kpalo et al. (2020) that the compressive strength should be 1.0MPa upward for briquette. The ability to be easily handled, stored and transported without damage was assessed using indices.

Table 3

Comparison of the Test Values with the 3 Existing Guides

Test	Sample	Guide 1 (ASTM)	Guide 2 (ISO)	Guide 3 Remarks	Test Result Researchers	Rating
Moisture Content (%)	AA				87.6	low good
	FF	≤ 8 - ≤15	≤ 8 - ≤15	≤ 8 - ≤15	7.33	low very good
	ZZ				7.02	low very good
Density (g/cm³)	AA				1.21	high very good
	FF	≥ 0.9 - 1.0≥	≥0.6-0.9≥	0.49- 0.82	1.33	high very good
	ZZ				1.16	high very good
Fixed Carbon (%)	AA				41.65	low not good
	FF	48 - 58	N/A	60-80	37.61	low not good
	ZZ				26.26	low not good
Volatile Matter (%)	AA				61.03	high good
	FF	85	N/A	60-80	57.61	low not good
	ZZ				46.11	low not good
Calorific Value (MJ/kg)	AA				21.9	high very good
	FF	≥14.9 - 15.5≥	≥14.5	≥14.9	22.3	high very good
	ZZ				1.4	high very good
Ash Content (%)	AA				55	high not good
	FF	≤12.53≤50.54	≤6-≤10	≤15 - ≤50	63.8	high not good
	ZZ				57.6	high not good
Compressive Strength (N/mm²)	AA				1.25	high very good
	FF	1.0	N/A	1.0-4.0	3.12	high very good
	ZZ				2.89	high very good

The results recorded from the various tests conducted in this study by the three companies, AA, FF and ZZ, were compared with existing standards for producing more durable, stable and quality briquettes and were rated based on their results as shown in Table 3, respectively.

Fig. 7.
a-d - The graph presents the result of the combustion and the physical and mechanical properties of the briquettes.

CONCLUSIONS

This study compared the Moisture content, Density, Compressive strength, Calorific value, Ash content, Fixed carbon content and the percentage of Volatile matter of briquettes produced by three production companies with some existing standards to determine their quality. Using statistical tools aided in interpreting the results recorded about the relationships between the samples and the existing guides. Generally, the findings indicate that all three companies recorded moisture contents, densities, calorific values and compressive strength, which were all classified as good and very good according to the indices adopted for the study. Alternatively, samples FF and ZZ recorded values classified as “not good” for the percentage of fixed carbon and volatile matter, except sample AA, which recorded a high percentage of volatile matter and was classified as good. However, their values were not very far from the range. Based on the results from this study, it can be concluded that company FF produces higher quality briquettes, followed by company AA and ZZ, respectively. Due to the naturally high combustion properties in coconut waste, higher values were expected in this study, resulting in the conclusion that the values obtained were not impressive. Higher-quality products can be produced if followed by the right production techniques and procedures. It can also be concluded that using coconut waste and cassava starch for briquette production is highly recommendable as it helps provide renewable, clean and sustainable energy; it will also reduce the pressure on the forest and substitute for fuel-wood and charcoal.

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