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Investigation of the Mechanical and Combustion Characteristics of Cocoa Pod and Coconut Husk Composite Briquette

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The majority of Ghana's population uses wood biomass as a source of energy, but as energy demand rises, the forest cover will no longer be able to provide the need. As a result, there is a pressing need to look for sustainable alternative energy sources. The project is focused on the mechanical and combustion characteristics of coconut husk and cocoa pod composite briquette. Dry coconut husk and cocoa pod were collected, carbonized at a temperature of 450ºC and hammer milled. They were then mixed into various mixture ratios at the required particle sizes and bonded together with the help of starch before manually compacting them into the desired shape. The resulting composite briquette were dried for a week before determining their mechanical and combustion characteristics. CNH: CCP 20:80 was the best mix ratio, with the highest calorific value (25.83 MJ/kg), good moisture and ash content, as well as good density and durability index. The density of the briquettes increased from 389 Kg/m^3 to 608 Kg/m^3 at 100:0, 80:20, 60:40, 50:50, 40:60, 20:80, 0:100 (CNH: CCP); the durability index increased from 97.36% to 99.96% when the cocoa pod was increased. Moisture content, ash content, as the cocoa pod mix ratios were decreased from 6.43%, 5.14%, and 10.12% to 4.53%, and calorific value increased from 17.73MJ/kg to 25.83 MJ/kg respectively. The analysis of the production cost of briquettes revealed that 1 kg of briquettes should be sold at Gh¢3.11 in order to make a 10% profit. The resulting briquettes may be used as an alternative energy source since they exhibited mechanical and combustion properties that were comparable to those of wood and charcoal.

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Keywords: Briquette; coconut husk; cocoa pod; moisture content; calorific value; biomass, ash content; durability index.

1. INTRODUCTION

Rapid industrialization in both industrialized and emerging countries has boosted global energy demand and consumption [1]. Wood fuels such as firewood and charcoal have traditionally been utilized for household activities such as cooking in most underdeveloped nations [2]. The increased use of fossil fuels has contributed significantly to climate change, prompting a quest for environmentally benign and renewable energy sources such as biomass [3].

Other types of biomass, which have a lot of potential as bioenergy feedstocks because they're available in big quantities as waste [4], are one of Ghana's most promising renewable energy sources for replacing fuelwood.Agricultural wastes such as maize stalks, rice husks, and palm kernel shells are used to create biomass waste., sawdust, cotton stalks, cocoa pods, groundnut husks, and coconut husk is plentiful in Ghana and has been used as a cooking alternative [3].

"Because of the bulkiness and aggravation that this rubbish can cause to the environment, converting such waste materials into biofuels may help to reduce landfill disposal volume and pollution" [5]. "Because of the characteristics of biomass residues in their natural state, such as high moisture content, poor heat output, and smoke formation after combustion, employing biomass residues as bioenergy is difficult" [6]. Briquette technology, which adds value to biomass fuels while boosting their heat value [7], is one of the most promising answers to the problems that biomass leftovers provide. According to the Ghana Living Standards Survey [8] wood fuel is used by nearly three-quarters of rural households (74.8 percent), which includes charcoal and firewood.

"As a result of the bulkiness and annoyance that degraded Ghana's forest reserve and the country, converting such waste materials into biofuels could help to reduce landfill disposal volume and pollution. According to this poll, charcoal was used as a source of energy by the majority of Ghanaian homes. Despite the fact that charcoal is a low-cost energy source that provides a source of income for many people in rural and urban regions, its widespread use has devastated Ghana's forest reserve and the country's general environment. In recent years, over-exploitation of the forest reserve for charcoal manufacturing, firewood, and furniture has resulted in a 3% annual reduction in Ghana's forest cover" [9]. As a result, alternative energy sources that are both environmentally acceptable and accessible must be created. Coconut husk and cocoa pod, formerly regarded as waste, might be used as an alternative fuel source. Although research has been done on the mechanical and combustion properties of many types of biomass, nothing is known about composite briquettes made from coconut husk and cocoa pod. The mechanical and combustion properties of coconut husk and cocoa pod composite briquettes were investigated in this work

2. MATERIALS AND METHODS

2.1 Production of the Briquettes

Cocoa Pod (CCP) was obtained from Kumasi, while Coconut Husk (CNH) was obtained from Texpo market Spintex-Accra with a moisture content of around 28%. The starch used as a binder was purchased from Madina's local markets. Due to their availability and the fact that they are dumped as trash with no further economic value after fruit extraction, Cocoa Pod and Coconut Husk were chosen.

Academic City University's Department of Mechanical Engineering performed the hammer mill and screening. To optimize the carbon yield for higher heat value, the shells were carbonized in a muffle furnace at Academic City University's Department of Mechanical Engineering at a regulated temperature of 400℃ for 45 minutes in compliance with ASTM D 2677. In the Mechanical Engineering workshop, the carbon fines were combined with the binder and crushed. The briquettes were then bagged and labeled before being carried to the engineering storeroom to dry.

The density and durability index were determined because they have an impact on solid fuel packaging, handling, transportation, storage, and use. Because of their impact on fuel quality, calorific value, ash content, and moisture content were identified as combustion characteristics. The Parr 6200 bomb calorimeter, muffle furnace, digital weighing scale, and Vanier caliper were all available in the Mechanical Engineering Department.

2.1.1 Preparation of raw materials

According to Gimba and Gimba [10], "cocoa pods and coconut husk were sun-dried separately to about 5% moisture content and hammer milled before carbonizing at 400℃ for 45 minutes in a muffle furnace. In the desiccator, the carbonized materials were cooled to room temperature". "The materials were sieved to different particle sizes of 3 mm, 5 mm, and 7 mm after cooling", as suggested by Zhang et al. [11]. To avoid moisture absorption from the atmosphere, the sieved components were packed and sealed in separate marked plastic bags. The mold had a diameter of 28 mm and a length of 120 mm.

Separate portions of CCP and CNH were removed from their containers, weighed using digital scales, then combined in water with banana peel paste in a mortar, then pounded with a pestle until a fine paste was obtained. The sample was 20 grams in total.

"The binder weight was kept at 50% of the sample mix weight, which was determined by trial and error and accords with the findings of Davies and Davies [12] for the optimal binder ratio".

Fig. 1. Briquette making process

2.1.2 Preparation of molds and dies

A mild steel cylinder bar section was used to make a cylindrical mold with a diameter of 28 mm and a length of 120 mm. To reduce friction during the briquetting process, the inside bore's surface was smoothed using fine emery paper.

Fig. 2. mold and die

2.2 Effect of Mix Ratios on Mechanical Characteristics of Briquettes

2.2.1 Density

This is one of the most significant mechanical and combustion qualities that determine how solid fuel is handled, stored, and transported. Briquette density was evaluated using ASAE S269.4 criteria. Because density is a property of mass against volume, the following procedure was used to determine briquette density. Using Vanier calipers, the height and diameter of a briquette were measured at six 90-degree angles.

In each example, the average of the measurements was calculated and used to determine the height (h) and diameter (d). Briquette density was then calculated using equation 3.1 0.

$$\rho = \frac{m}{v} \qquad (2.1)$$

Where ρ = density (g/cm^3)
m = mass (g)
v = volume of the briquette (cm^3)

2.2.2 Durability index tests

The chartered index provided by Suparin et al. [13] was used to determine how long the briquettes will last. The briquette samples were repeatedly dropped onto a solid foundation from a height of 1.5 meters. Briquette breakability was measured by the percentage of the briquette that was kept. A portion of the sample disintegrated after being dropped from 1.5 meters. After that, the remaining amount was reweighed. The briquette's durability was measured as a percentage of the material left on the metal plate compared to the initial mass.

$$\text{In} = \left(\frac{m_1 - m_2}{m_1}\right) \qquad (2.2)$$

2.3 Effect of Mix Ratios on Combustion Characteristics of Briquettes

The moisture content, calorific value, and ash content of the briquettes were examined in order to determine their suitability as a fuel.

2.3.1 Determination of moisture content

The moisture content was measured according to the ASTM D3173-11 standard. For 1-hour, empty crucibles were heated to 105 degrees. They were then taken out of the oven, covered, and cooled for 30 minutes in the air to room temperature. One gram of each sample was weighed, placed in the crucibles, and dried for 24 hours at 105 degrees. The crucibles were weighed again after cooling in desiccators to room temperature. The moisture content is the difference in mass. As seen in equation 3.3, this was expressed on a wet basis.

$$\text{Moisture content} = \left(\frac{Wet\ weight - Dry\ weight}{Wet\ weight}\right) * 100 \qquad (2.3)$$

2.3.2 Determination of calorific value

The energy content of biomass is determined by its calorific (heating) value. The gross calorific value of the briquettes was determined using a Parr 6200 oxygen bomb calorimeter (Parr Instrument Company, Moline, IL). A cotton fuse ignited the material in the vessel (bomb) after one gram was placed in a stainless-steel crucible. The vessel was encased by a water jacket and was filled with oxygen. The released heat is transmitted to the water jacket after ignition.

The calorimeter used the temperature rise in the water jacket to compute the sample's heating value. Each sample's tests were repeated five times. This experiment used the ASTM Standard D5865-03 (ASTM 2003b) test technique for gross calorific value.

$$\text{GCV} = \frac{(W1+W2)*s*(t2-t1)}{m} \qquad (2.4)$$

Where
W1= mass of water in calorimeter (Kg)
W2 = water equivalent of the calorimeter (Kg)
S = specific heat of water (KJ Kg^{-1}℃)
(t2-t1) = change in temperature (℃)
m = mass of the briquette (Kg)

2.3.3 Determination of ash content

Ash is the residue left over after biomass has been burned. The ash content was determined using the ASTM E 830-87 standard, which required one gram of the sample to be placed into a weighted crucible. The crucible containing the sample was placed in the muffle furnace and gradually heated to 725℃ before being left for 1 hour. The crucible was taken out of the oven and placed in a desiccator to cool. The difference in weight represents the ash content, which was calculated using equation 2.4.

$$\text{Ash content (\%)} = \frac{A - B}{C} * 100 \qquad (2.5)$$

Where
A is the mass of the crucible ash and residues (g)
B is the mass of empty crucible (g)
C is the mass of the sample used (g)

2.4 Data Analysis

This study used a Randomized Complete Design. Six composite briquette mixture ratios and three particle sizes were investigated. For each condition, 36 samples were examined. The researchers employed descriptive statistics, analysis of variance, and Duncan Multiple Range Tests. Microsoft Excel was used to conduct all of the analyses. The Least Significant Difference technique LSD was set at 0.05 for mean separation.

3. RESULTS AND DISCUSSION

3.1 Production of Briquettes

The briquettes were made from a mixture of cocoa pods and coconut husk, which were crushed and carbonized at 400°C by ASTM D2677. Before briquetting, the carbonized fines were bonded with 50% cassava starch, as advised by Suparin et al. [13] for the optimal binder ratio. The briquettes were then dried and wrapped in labeled plastic bags before being evaluated for mechanical and combustion properties.

3.2 Effect of Mixture Ratios on Mechanical and Combustion Characteristics of Briquettes

The results of combustion and mechanical testing on briquettes with various mixture ratios are tabulated and analyzed below.

3.2.1 Mechanical characteristics

3.2.1.1 Density

Density is an important characteristic of fuel. It provides evidence of energy density. The results (Table 1) illustrate the briquette density for various combination ratios. From the outcomes, the density was 389 Kg/m3 for 100:0 mix ratios of CNH: CCP but increased to 608 Kg/m3 for 0:100 mix ratios. This could be attributed to characteristics of the original materials which were the coconut husk and cocoa pod. This supports the findings of Chirchir et al. [14], who discovered that different material ratios directly affect densities. It also demonstrates that the density of cocoa pod is larger than that of coconut husk.

The density varies significantly at all mix ratios, as shown by Table 2 and Fig. 3, with an LSD of 89.24 and a correlation factor of 0.1112 respectively.

3.2.1.2 Durability index

The briquette's durability index is measured as a percentage of the initial mass of the material left on the metal plate. It shows how the particles joined throughout the briquette manufacturing process. The durability index ranged from 96.67% to 99.96% based on the results. Except for the mix ratio of 100:0, the mix ratios did not affect the durability index. This means that the composition ratios had no meaningful effect on the bonding effect of the adjacent particle. The impacts of mix ratios on the durability index are shown in Table 2 and Fig. 4.

Table 1. Density (Kg/m3) of briquette at different mix ratios

Mixture ratios (CNH: CCP)	Mean density (Kg/m3)
100:0	389^{a}
80:20	438^{b}
60:40	477^{c}
50:50	502^{d}
40:60	522^{e}
20:80	566^{f}
0:100	608^{g}
Mean	482

Means followed by the same letter(s) (a,b,c,d,e,f,g) in same column are not significantly different α=0.05 using LSD = 86.24

Table 2. Durability index (%) of briquette at different mix ratios

Mixture ratios (CNH: CCP)	Mean Durability Index (%)
100:0	97.36^{a}
80:20	98.20^{b}
60:40	98.58^{c}
50:50	98.33^{d}
0:100	99.96^{e}
20:80	98.45^{f}
40:60	98.21^{g}
Mean	98.44

Means followed by the same letter(s) (a, b, c, d, e, f, g) in the same column are not significantly different α=0.05 using LSD 15.58

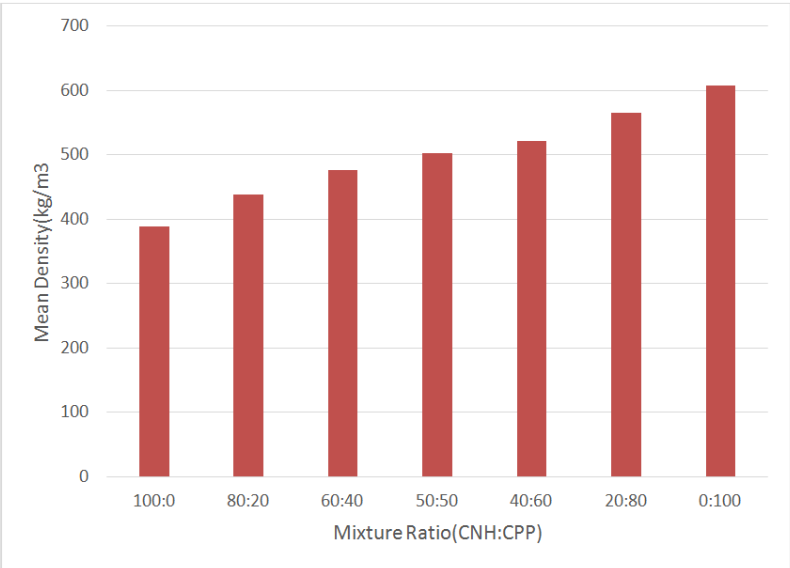

Fig. 3. Effect of mix ratios on the density

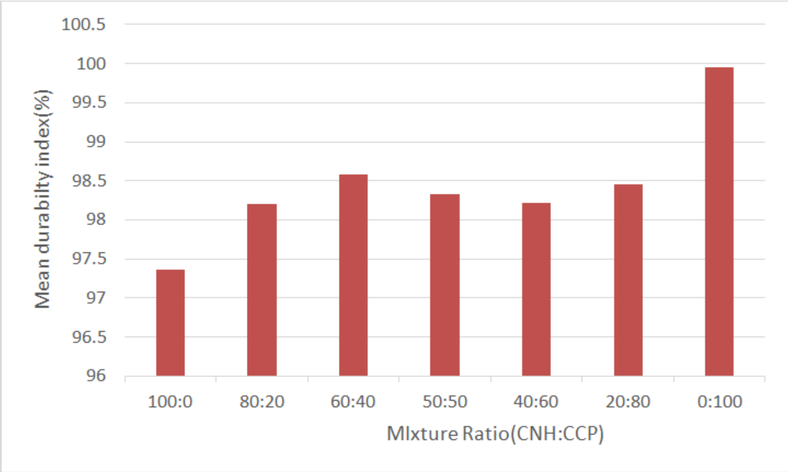

Fig. 4. Effects of mix ratios on durability index (%) of briquette

Briquette strength affects briquette durability because as strength increases, air humidity absorption decreases. Sotande et al. [15] discovered that "increasing the amount of binder and the type of binder has a substantial impact on the briquettes' durability index. The durability index of 98.74% obtained in gum Arabic bonded briquettes was higher than 83.26% obtained in starch bonded briquettes, and the values were statistically significant at the 5% probability level, which concurs with the findings of this study. The study's average durability index was 98.43%, which is comparable to that of the Gum Arabic binder. This indicates that the starch binder has strong adhesive properties".

3.3 Combustion Characteristics

3.3.1 Moisture content

Moisture content has an impact on the fuel's combustion properties. High moisture content is undesirable since it requires more heat to dry the fuel. The moisture content was 6.43% at the CNH: CCP 100:0 mix ratio, but decreased to 5.14% at the 0:100 ratio, according to the data. When the optimal mechanical qualities of briquettes were achieved, the moisture percentage of the input raw material should be between 4 and 10%. However, the maximum moisture content of some raw materials is 6-8 percent. The critical moisture content is the point at which briquettes can still be formed, but crack failures on their surface are common, and the briquettes lose their market value. The essential amount of water is between 10% and 15%. Briquette moisture is mostly determined by the starting moisture of the raw material, and it varies during the briquetting process, as some moisture escapes when the temperature rises due to compression. Briquettes with a high moisture level have a more consistent bed, more crumbles, a lower energy value, and thus a lower price [16]. The trends are shown in Table 3 and Fig. 5.

Table 3. Moisture content (%) of briquette at different mix ratios

Mixture ratios (CNH: CCP)	Mean Moisture Content (%)
100:0	6.43^{a}
80:20	6.23^{b}
60:40	5.98^{c}
50:50	5.83^{d}
40:60	5.68^{e}
20:80	5.26^{f}
0:100	5.14^{g}
Mean	5.79

Means followed by the same letter(s) (a,b,c,d,e,f,g) in same column are not significantly different α=0.05 using LSD = 15.58

The moisture content varied significantly with the mix ratios, as shown in Table 3 and Fig. 5, with an LSD of 15.58 and a regression coefficient of 97.18%. The briquettes had an average moisture level of 9.20%. This falls within the permissible operational moisture content range of 8–12% for briquetting, which is consistent with the [16] findings of a range of 6–12%. This is also consistent with [16] results that good grade briquettes should have moisture levels of 8-12%. Some materials, on the other hand, can have up to 20% moisture content and can be densified in a piston press.

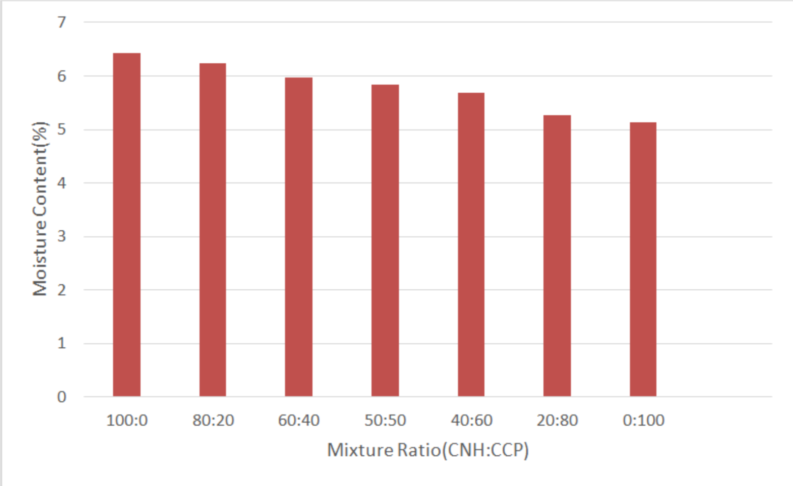

Fig. 5. Effects of mix ratios on moisture content (%) of briquette

3.3.2 Ash content

Higher ash concentration diminishes briquette efficiency and causes fire management issues, such as frequent ash removal from the stove. According to Table 4, the ash concentration was 10.12% at 100:0 CPP: CNH mixture ratios, but rose as the coconut husk content in the composite briquettes increased. The ash level of briquettes made only from coconut husk (0:100) was 10.12%. This demonstrated that the original material's ash content is a distinguishing feature. The ash contents at various combination ratios are shown in Table 4 and Fig. 6. This is in line with a study [17] that found briquette quality to be dependent on the material utilized.

Table 4. Ash content (%) of briquette at different mix ratios

Mixture ratios (CNH: CCP)	Mean Ash Content (%)
100:0	10.12^a
80:20	9.13^b
60:40	7.98^c
50:50	7.43^d
40:60	6.93^e
20:80	5.92^f
0:100	4.53^g
Mean	7.43

Means followed by the same letter(s) (a,b,c,d,e,f,g,h) in same column are not significantly different α=0.05 using LSD = 15.63

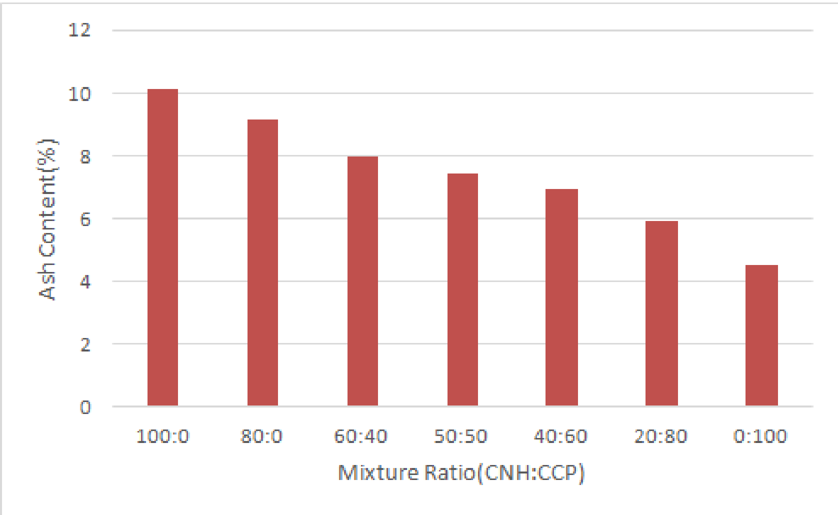

Fig. 6. Effect of mix ratios on the ash content

The mix ratios demonstrated a statistically significant effect on the ash content, with an LSD of 15.63. This shows that the qualities of the original materials play a considerable role in the amount of ash in fuel. Higher ash content in the fuel is undesirable since it reduces the calorific value of the fuel.

3.3.3 Calorific value

The calorific value (also known as the heating value) is a standard measurement of a fuel's energy content. When a unit weight of fuel is entirely burned and the combustion products are cooled to 298 K, it is defined as the quantity of heat released. The impacts of mix ratios on calorific values are shown in Table 5 and Fig. 7.

Table 5. Calorific value (MJ/kg) of briquette at different mix ratios

Mixture ratios (CNH: CCP)	Calorific Value
100:0	17.73^{a}
80:20	21.54^{b}
60:40	23.04^{c}
50:50	23.85^{d}
40:60	24.66^{e}
20:80	25.83^{f}
0:100	26.78^{g}
Mean	23.35

Means followed by the same letter(s) (a,b,c,d,e.f,g) in same column are not significantly different α=0.05 using LSD=15.63

From Table 5 and Fig. 7, the calorific value varied with the mixture ratios. As the amount CCP increase in the mixture ratios the calorific values increased from 17.73 MJ/kg to 25.83 MJ/kg and 23.35 MJ/kg respectively. These suggest that Coconut Husk had a lower calorific value than Cocoa Pod.

The mix ratios of Coconut Husk and Cocoa Pod had a substantial effect on the calorific values, with the LSD being 15.63 and the mean calorific value being 23.35 MJ/kg, according to the results. Based on the findings above, it was determined that all briquettes were generated to meet the minimum calorific value criteria for commercial briquette production (>17500 J/g).

Rice husk had a calorific value of 13,389 KJ/kg, while corncob briquette had a calorific value of 20,890 KJ/kg, according to earlier studies. These energy values are adequate for producing heat for domestic cooking and small-scale industrial cottage applications. They also compare favorably to the results of this study. For example, groundnut shell briquettes have a heating value of 12,600 kJ/kg [18], cowpea briquettes have a heating value of 14,372.93 kJ/kg, and soybeans have a heating value of 12,953 kJ/kg [19]. As a result of these findings, CNH calorific value at 17.73 MJ/kg and CCP calorific value at 26.78 MJ/Kg compare favorably to findings from other agricultural wastes [20-22].

3.4 Cost Analysis

Direct material costs and operating costs were used to compute the cost. Feedstock, starch, and water costs were stated as the direct material costs. The operational costs included labour, pyrolysis heat energy, charring equipment cost, moulding device cost, storage and packing cost. According to Table 6, 1 kg must be sold for Gh¢ 2.83 on the market in order to break even. However, the price should be set at Gh¢ 3.11 for a 10% profit margin.

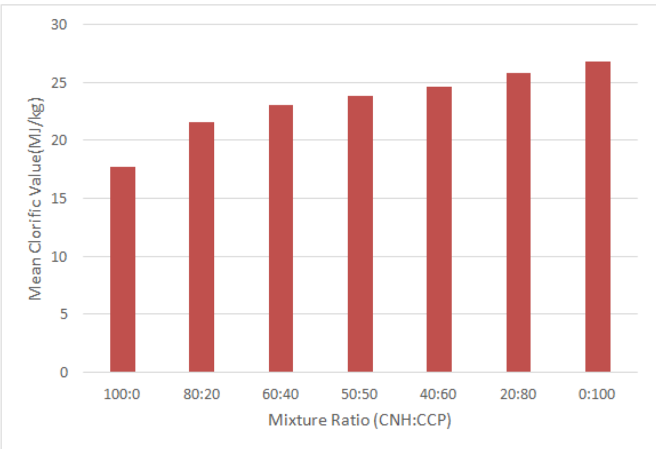

Fig. 7. Effects of mix ratios on the calorific value of the briquettes

Table 6. Cost Analysis

Material & Equipment	Cost(Gh¢)	Quantity used for Briquittes(kg)	Quantity of briquette Produced(kg)
Collection and Transportation of Feedstoch	4.5	10	6
Cassava Starch	2	1	
Purchasing of Water	1.5	5	
Moulding Unit	1	N/A	
Charring Unit	3	N/A	
Labour	5	N/A	
Total	**17**		
Cost of 1 kg(Gh¢)		**2.83**	

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The influence of changing cocoa pod and coconut husk mixture ratios were studied, as well as the mechanical and combustion characteristics of composite briquettes.

The best mix ratio was CNH: CCP 20:80, which had the highest CV, good moisture and ash content, good density, and durability index.

The density of the briquettes surged within the range of 389 Kg/m^3 to 608 Kg/m^3 at the ratios of 100:0, 80:20, 60:40, 50:50, 60:40, 80:40, 0:100 (CNH: CCP); durability index increased from 97.36% and to 99.96% and respectively as the cocoa pod was increased.

As the cocoa pod mix ratios were increased, moisture decreased from 6.43% to 5.14%, ash content decrease from 10.12% to 4.53% and calorific value increased from 17.73 MJ/kg to 26.78 MJ/kg, respectively.

4.2 Recommendations

For ease of handling and transportation, a good grade solid fuel should have a high calorific value, low moisture and ash content, high density, and a high durability index. Due to a good balance of ash concentration, moisture content, and calorific value, the sample with the optimum combination of all these features was a 20:80 mix ratio.

Further studies can be done to determine the following.

Physical properties of briquettes of various particle sizes, such as compacting pressure, compression strength, water absorption, and porosity index.

Impact of carbon monoxide emissions and carbonization temperature on briquette combustion and mechanical properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Goswam DY, Kreith F. Global Energy System. In: Handbook of Energy Efficiency and Renewable Energy, Taylor and Francis Group, LLC, Boca Raton, FL,1-20; 2007. Available:https://doi.org/10.1201/9781420003482.ch1
2. Emerhi EA. Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. Advances in Applied Science Research. 2011;2(6):236-46.
3. Akowuah JO, Kemausuor F, Mitchual SJ. Physico-chemical characteristics and market potential of sawdust charcoal briquette. International Journal of Energy and Environmental Engineering. 2012;3(1):1-6. Available:https://doi.org/10.1186/2251-6832-3-20
4. Phonphuak N, Thiansem S. Using charcoal to increase properties and durability of fired test briquettes. Construction and Building Materials. 2012;29:612-8.

Available:https://doi.org/10.1016/j.conbuildmat.2011.11.018
5. Amaya A, Medero N, Tancredi N, Silva H, Deiana C. Activated carbon briquettes from biomass materials. Bioresource Technology. 2007;98(8):1635-41. Available:https://doi.org/10.1016/j.biortech.2006.05.049
6. Suhartini S, Hidayat N, Wijaya S. Physical properties characterization of fuel briquette made from spent bleaching earth. Biomass and Bioenergy. 2011;35(10):4209-14. Available:https://doi.org/10.1016/j.biombioe.2011.07.002
7. Wilaipon P. Density equation of bio-coal briquettes and quantity of maize cob in Phitsanulok, Thailand. American Journal of Applied Sciences. 2008;5(12):1808-11. Available:https://doi.org/10.3844/ajassp.2008.1808.1811
8. Ghana Statistical Service. Ghana Living Standard Survey Round 6 (GLSS6); 2014.
9. Trossero MA. Wood energy: the way ahead. Unasylva. 2002;53(4):3-12.
10. Gimba CE, Muyiwa T. Optimum conditions for carbonisation of coconut shell. Scientia Africana. 2008;7(2). ISSN 1118-1931.
11. Zhang Y, Ghaly AE, Li B. Physical properties of corn residues. American Journal of Biochemistry and Biotechnology. 2012;8(2):44-53.
12. Davies RM, Davies OA. Physical and combustion characteristics of briquettes made from water hyacinth and phytoplankton scum as binder. Journal of Combustion. 2013;2013.
13. Chaiklangmuang S, Supa S, Kaewpet P. Development of fuel briquettes from biomass-lignite blends. Chiang Mai J. Sci. 2008;35(1):43-50.
14. Chirchir DK, Nyaanga DM, Githeko JM. Effect of binder types and amount on physical and combustion characteristics. International Journal of Engineering Science and Technology. 2013;2(2):12-20.
15. Sotannde OA, Oluyege AO, Abah GB. Physical and combustion properties of briquettes from sawdust of Azadirachta indica. Journal of Forestry Research. 2010;21(1):63-7.
16. Li Y, Liu H. High-pressure densification of wood residues to form an upgraded fuel. Biomass and Bioenergy. 2000;19(3):177-86.
17. Enweremadu CC, Ojediran JO. Evaluation of energy potential in husks from soy-bean and cowpea. 2004;8:18-23.
18. Mitchual SJ, Frimpong-Mensah K, Darkwa NA. Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. International Journal of Energy and Environmental Engineering. 2013;4(1):1-6.
19. Tokan A, Sambo AS, Jatau JS, Kyauta EE. Effects of particle size on the thermal properties of sawdust, corncobs and Prosopis Africana charcoal briquettes. American Journal of Engineering Research (AJER). 2014;3(8): 369-74.
20. Mitchual SJ, Frimpong-Mensah K, Darkwa NA. Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. International Journal of Energy and Environmental Engineering. 2013;4(1):1-6.
21. Tooy D, Nelwan L, Pangkerego F. Evaluation of biomass gasification using coconut husks in producing energy to generate small-scale electricity. In Proceedings of the International Conference on Artificial Intelligence, Energy and Manufacturing Engineering (ICAEME'2014), Kuala Lumpur, Malaysia. 2014;9-10.
22. Habib U, Habib M, Khan AU. Walailak Journal Sci & Tech. 2014;11(1):1-5.

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