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Proximate and Ultimate Analysis of Hybrid Briquettes Produced from Rice Husk and Corn cob Using Gum Arabic as a Binder

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ABSTRACT

The utilization of agricultural waste for the production of hybrid briquettes as alternative energy sources is desirable due to its potential to address waste disposal challenges, environmental degradation, and deforestation associated with fuel wood use. This study evaluated the performance of hybrid briquettes produced from rice husk and corn cob for use in a charcoal stove. Briquettes were produced from rice husk and corn cob residues, characterized through proximate and ultimate analyses, and compared with commercial wood charcoal. The residues were collected, pulverized to a particle size of 2.0 mm, and blended at mixing ratios of 100:0, 0:100, 80:20, 70:30, 60:40, and 50:50 (rice husk: corn cob). Gum Arabic (80g by weight) was used as a binder, and the mixtures were densified into cylindrical briquettes using a manually operated hydraulic press fitted with a compaction cylinder. The briquette produced from the 0:100 ratio exhibited the highest moisture content (3.6%), while the 50:50 blend recorded the highest ash content (10.9%) and volatile matter (28.0%). The 100:0 briquette showed the highest fixed carbon content (68.2%). In terms of ultimate analysis, the 50:50 blend had the highest hydrogen (4.4%) and oxygen (9.6%) contents, whereas the 100:0 briquette recorded the highest carbon (79.5%) and nitrogen (1.7%) contents. The highest sulphur content (0.013%) was observed in the 50:50 briquette. Overall, the results demonstrate that hybrid briquettes produced from rice husk and corn cob are viable, environmentally friendly, and sustainable alternatives to conventional fossil fuels and wood charcoal for domestic cooking applications.

Keywords: Rice husk; Corn cob; Binder; Densification; Briquettes.

1.0 INTRODUCTION

Energy plays a critical role in national development, contributing significantly to economic growth and the social well-being of a nation. However, the world is currently facing a growing energy shortage, a challenge that is particularly evident in developing countries such as Nigeria [1]. The household cooking sector represents the largest share of energy consumption in Nigeria, with over 70% of the population relying predominantly on firewood, especially in rural communities, where dependence continues to increase [1]. Nigeria's energy mix comprises several sources, including hydro, thermal, wind, solar, and biomass.

Nevertheless, rapid population growth has intensified the demand for energy for cooking, lighting, food processing, and industrial activities.

The increasing pressure on conventional energy sources has necessitated a gradual transition from fossil fuels to renewable and sustainable alternatives. Agricultural residues, in particular, present significant potential as renewable energy resources capable of contributing meaningfully to alternative energy generation [1]. Escalating prices of kerosene and cooking gas, coupled with the growing demand for fuel wood, further underscore the urgency of identifying affordable and sustainable energy options for both domestic and industrial applications. Addressing the persistent need for environmentally friendly, accessible, and cost-effective cooking energy is essential in reducing dependence on firewood and mitigating associated environmental challenges [2].

The indiscriminate felling of both economic and non-economic trees for cooking purposes, often without replacement, has accelerated desert encroachment and poses serious threats to forest ecosystems [3]. This practice contributes significantly to deforestation, environmental degradation, and increased greenhouse gas emissions. Furthermore, the combustion of fossil fuels for electricity generation has been identified as a major source of environmental pollution with emphasis on the advantages of renewable energy sources over fossil fuels. Their study also proposed short-term measures to alleviate energy challenges, including subsidizing solar technologies, upgrading fossil fuel power plants, and decentralizing power distribution from the national grid [4].

Recent studies have shown that Nigeria is endowed with abundant agricultural and household wastes that can be effectively converted into solid fuel briquettes for cooking applications in both rural and urban areas. The utilization of these wastes as alternative energy sources is highly desirable, as it addresses waste management challenges, alleviates energy shortages, and reduces air pollution. Consequently, the conversion of agricultural residues into briquettes offers a sustainable and environmentally responsible pathway for meeting household energy demands while preserving natural resources. Therefore, this study aims to produce sustainable hybrid biomass briquettes from rice husk and corn cob and to evaluate their suitability as an alternative solids' fuels. Specifically, the research seeks to comprehensively characterize the combustion properties of the produced briquettes. By correlating material composition with performance indicators, the study provides scientific insight into the optimization of briquette quality and to support the utilization of agricultural residues for efficient energy applications.

2.0 MATERIALS AND METHODS

2.1 Materials and equipment

The raw materials used for this work were, rice husk, corn cob and gum Arabic as a binder. Both the rice husks and corn cobs were obtained in many farms and waste dumps in Jalingo local government area of Taraba state and environs. The rice husks were in abundance at the rice mill industries located at various places within the local government area. The rice husks are piled in heaps after milling the rice paddy and are dumped randomly over the places. The binder was obtained at Jalingo market in Jalingo Local Government Area of Taraba State, Nigeria. The commercial wood charcoal was also obtained within the local government area. While the equipment used includes muffle furnace, hot air oven, tube furnace, hydraulic press machine, electronic universal testing machine and mechanical mixer.

2.2 Formulation and production of briquette samples

The collected rice husk and corn cob materials were dried under the sun for a day in other to reduce moisture content from the materials. The materials were reduced into smaller particles through pulverization which

was achieved by using wooden mortar and pestle. The mixing ratios of [5] was adopted which expressed rice husk: corn cob as 100:0, 0:100, 80:20, 70:30, 60:40 and 50:50 respectively. 80g of the binder was used constantly throughout the densification process for the different mixing ratios on weight basis. Commercial wood charcoal of 100g was used as a control which equals the ratios of the rice husk and the corn cob. The pulverized materials were sieved using 2mm sieve size as suggested by [5]. The gum Arabic (Acacia Senegal) in its granular state was pounded using the same mortar and pestle used during the material preparations and was soaked in water for 2 days as suggested by [2]. The gum Arabic was mixed with water to create a solution and was sieved with a sieve size of 1mm. Each sample ratio was weighed separately using digital weighing balance (Model CS 5000 with Capacity of 5000g x 1g) and also mixed separately using a mechanical mixer of 0.25kw operating at 100 r/min was used for proper mixing as suggested by [6]. The mixture was unloaded from the mixer to a container for onward densification. The nature of the briquettes produced was cylindrical in shape. According to [7] briquettes of cylindrical shape are generally between 18 and 55mm in diameter and 10 to 100mm in length. Therefore, the produced briquettes have a diameter of 50mm with a length of between 85 - 95mm. Figure 1 shows rice husk waste before pulverizing while Figure 2 shows corn cob waste before pulverizing.



Figure 1 Rice husk waste before pulverizing



Figure 2 Corn cob waste before Pulverizing

2.3 Briquetting process

The compaction of the materials was done using hydraulic press machine domiciled in a fabrication workshop in Jalingo, Nigeria as shown in figure 3. A compaction mould was mounted on the hydraulic press in which the materials were compacted conveniently. The holding time of each briquette was 180s

which allows the formed briquette to fuse together. Figure 4 shows the process of ejecting the briquette from the cylinder.



Figure 3. Feeding the cylinder with the mixed Material



Figure 4. Receiving the briquette material

The briquettes were then sun-dried for three days to remove moisture and then cured at room temperature. Figure 5 shows the samples of the produced briquette from different mixing ratios. While figure 6 shows the drying process of the sample briquettes.



Figure 5. Drying process of the briquettes



Figure 6. Samples of the briquettes

2.4 Determination of compaction ratio (CR)

Compaction ratio is the ratio of the loose volume of material before compaction to its compacted volume after compaction. It's a measure on how much the material has been compressed. Mathematically,

Compaction ratio denoted by (CR) = $\frac{Volume\ of\ the\ loss\ material}{Volume\ of\ the\ compacted\ material}$

$$CR = \frac{v_1}{v_2} \quad (1)$$

Where, $V_1 = \pi r^1 h_1$ and $V_2 = \pi r^2 h_2$

V_1 = volume of the loss material in the briquetting cylinder

V_2 = volume of the compacted material in the briquetting cylinder

r = radius of the briquetting cylinder

h_1 = height of the loose material in the briquetting cylinder (before compaction)

h_2 = height of the compacted material after ejection (briquette)

The compression ratios of all the samples (1-6) were computed using equation (1) above.

2.5 Characterization process

Characterization of briquette refers to the process of analysing the briquettes properties in order to determine their quality and sustainability for various applications, such as energy production and as fuel for domestic usage. The combustion properties that were characterized are proximate and ultimate analysis.

2.6 Determination of Proximate analysis of the briquette by percentage wet basis

Proximate analysis is a characterization method used to determine the basic properties of a briquette which includes moisture content, volatile matter, fixed carbon and ash content. This analysis involves careful heating of briquette samples under controlled conditions to assess its composition which is essential for evaluating and sustainability for various applications.

2.6.1 Moisture content

The moisture content of the briquettes was determined using the standard technique, (ASTM D2019). The sample was weighed to obtain the quantity of 5g. The sample was placed in hot air oven and the temperature

was set at 135ºC and it was removed after reaching two hours of heating which was cooled in a desiccator. The sample was reweighed after 15minutes of cooling to determine the moisture content. The test was repeated twice and the average values were taken [8].

$$\text{Percentage moisture content} = \frac{g-X}{g} \times \frac{100}{1} \quad (2)$$

Where g = weight of sample before oven drying in (gram), X = weight of dry sample after oven drying in (gram) and g - *X* = loss in weight of the sample briquette in (gram).

2.6.2 Volatile matter content

The percentage volatile matter (PVM) was obtained using the standard techniques, (ASTM D3175). The sample was weighed to obtain 2g and placed in tube furnace. The temperature was set at 135ºC for two hours and heated up to 900ºC for 10 minutes then cooled in a desiccator for 15 minutes. The sample was reweighed to determine the volatile matter content. The test was repeated twice and the average values were taken and calculated using the equation below

$$\text{Percentage volatile matter} = \frac{x-y}{g} \times \frac{100}{1} \quad (3)$$

Where g = weight of sample in (gram), x = weight of dry matter in (gram) and y = weight of residue in (gram).

2.6.3 Ash content

Ash content was determined using the standard technique, (ASTM D1762). The sample was weighed to obtain 2g and placed in a muffle furnace. The temperature was set at 700ºC. The sample was removed after reaching one hour of heating and cooled in a desiccator and reweighed to determine the ash content. The test was repeated twice and the average values were also taken. The values were calculated using the equation below [4].

$$\text{Percentage ash content} = \frac{x}{g} \times \frac{100}{1} \quad (4)$$

Where x = weight of the ash in (gram) and g = weight of sample in (gram).

2.6.4 Fixed Carbon Content

The percentage fixed carbon was determined using the standard technique, (ASTM D3175) by adding up the values of PMC, PAC and PVM and their results were subtracted from 100% [10].

$$\text{Percentage fixed carbon} = 100 - \%MC + \%VM + \%AC \quad (5)$$

Where;

MC = Moisture content, VM = Volatile matter and AC = Ash Content

2.7 Determination of Ultimate analysis of the briquette by percentage wet basis

Ultimate analysis is also a characterization method used to determine the weight percentage of the elemental composition of material. The amount of carbon, hydrogen, sulphur and nitrogen are determined

in the combustion products resulting from complete combustion. Oxygen is determined directly by subtracting the weight of the other elements from total as reported by [9].

2.7.1 Hydrogen content of the briquettes

The hydrogen contents of the samples were determined using Equation (6) below:

Hydrogen Content (%)

$$= [(0.036\ FC) + 0.086\ (VM - 0.1\ AC) - (0.0035MC2)\ (1 - 0.02MC)] \quad (6)$$

Where;

MC = Moisture content, VM = Volatile matter and AC = Ash Content

2.7.2 Carbon content of the briquettes

The carbon contents were determined using Equation (7) below:

$$\text{Carbon content (\%)} = [(0.97FC) + 0.7(VM - 0.1) - MC\ (0.6 - 0.01)] \quad (7)$$

Where;

FC = percentage fixed carbon content (%), VM = percentage volatile matter (%) and MC = percentage moisture content (%)

2.7.3 Nitrogen content of the briquettes

The nitrogen contents were also determined using equation (11 below):

$$\text{Nitrogen content (\%)} = 2.10 - 0.020VM \quad (8)$$

Where;

VM = percentage volatile matter (%)

2.7.4 Oxygen content of the briquettes

The oxygen contents were also calculated using Equation (12) below:

$$\text{Oxygen Content (\%)} = 100 - (C + H + N + AC) \quad (9)$$

Where;

C = Carbon content (%), H = Hydrogen content (%), N = Nitrogen content (%)

AC = Ash content (%)

2.7.5 Sulphur content of the briquettes

The sulphur was determined from the equation below;

$$\text{Sulphur content (\%)} = {SO_4}^{2-}(mg.kg^{-1})\ to\ S\ = \frac{ABS \times DF \times DV \times G}{wt \times A} \quad (10)$$

Where;

ABS = Absorbance reading, DF = Dilution factor (Distilled water),

DV = Digestion volume, G = Gradient from the calibration curve, wt = Weight of sample,

A= Aliquot taken and 0.333 = conversion factor from $SO_4^{2-}(mg.kg^{-1})\ to\ S$

3.0 RESULTS AND DISCUSSION

3.1 Proximate analysis

The results of proximate analysis is shown in Table 1.

Table 1 Proximate analysis of the briquette and comparing with that of wood charcoal in gram (g)

Sample properties of the briquette	Sample ratio (RH:CC)						
	1	2	3	4	5	6	7
	100:00	00:100	80:20	70:30	60:40	50:50	100
Proximate analysis							
Moisture content (%)	2.0	3.6	3.0	3.2	3.0	3.4	1.4
Ash content (%)	9.0	10.7	10.1	10.5	10.6	10.9	0.5
Volatile matter (%)	20.8	23.8	23.6	24.2	26.6	28.0	29.6
Fixed carbon content (%)	68.2	61.9	63.3	62.1	59.8	57.7	68.5

The Proximate analyses graph estimates how the sample ratios behave in combustion, the graph determines approximate amount of water present in the samples and amount of inorganic residue left after combustion.

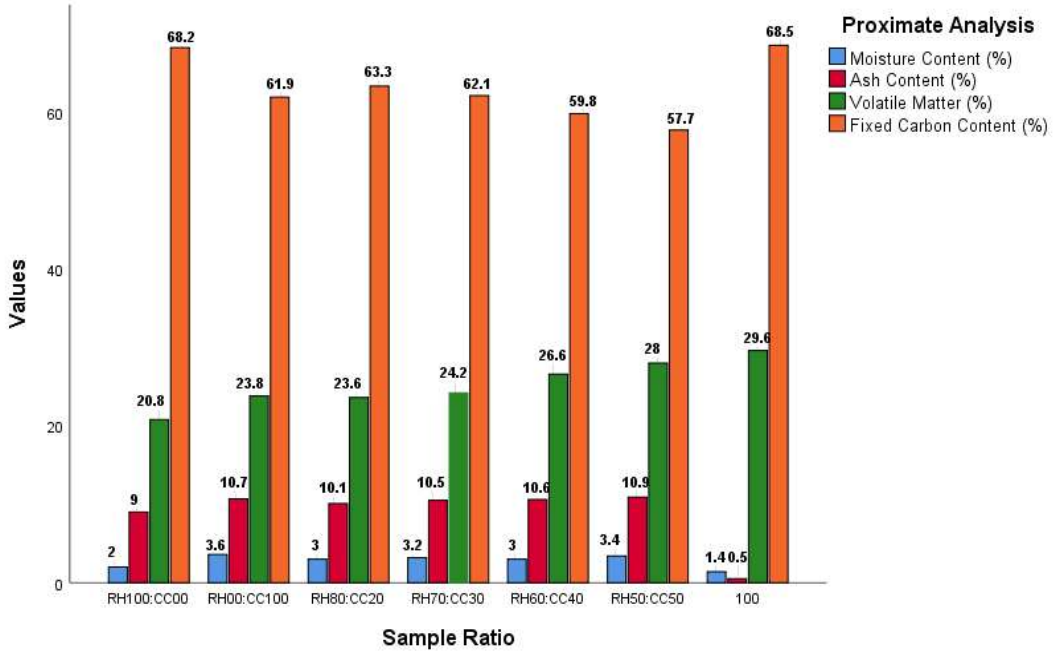


Figure 7: Effects of input variables on proximate analyses of the briquettes

3.1.1 Moisture content

The lowest moisture content of 2.0% was obtained from ratio (Rh100:Cc00), although, the value is low but it enhances ignition with a high calorific value. Moisture content increases with corncob proportion, but values remain relatively low. Moisture content remains relatively low across all ratios, indicating good briquette quality. The result obtained is lower than that of [10] for briquettes produced from a blend of rice husks and palm kernel shells as an alternative solid fuel and [11] for briquettes produced from Oxytenanthera abyssinica, arundinaria alpine, Acacia melifera and Prosopis juliflora and with values between (5.54% – 4.18%) and (5.29% – 5.0%) respectively. The findings also supports the work of [12] in which good quality briquettes should have a moisture content less than 20% which is the required standard for the briquette. The results also agreed with [1] whose values were between (9.24% – 10.00%). Briquettes with lower moisture content are expected to light easily and should have heating values as higher moisture content produces smoke and results to low burning rate.

3.1.2 Ash content

As also seen from the graph, Sample 1 (Rh100:Cc00) had the lowest ash content at 9.0%, while Sample 6 (Rh50:Cc50) had the highest ash content at 10.9%. The values of ash content increases with corn cob proportion due to the corn cob's high ash content. Low ash content reduces emissions and correlates with higher heating value, while high ash content leads to lower heating value. The findings of this research are far below to that of [10] having values between 19.32% - 12.48% in contrast to the above, Cavallo and Pampuro (2017) reported that the value of ash content obtained was between 3.37% - 4.91% for briquettes made from hybrid Poplar, chest nut and mixture of Spruce white pine. The lower value realized suggest that, impurities in the sample briquettes are few thereby allowing energy releases during combustion which in turns enhances the calorific value of the briquette [13]. The higher ash content in corn cob – rice blends might require more frequent ash removal and handling. Higher ash content was also acquired in the findings of [14] with a value of 30.3% - 33.8%. The average ash content obtained from the experiment for the samples was 10.3% which was higher to that of the control (wood charcoal) that has 0.5% which can also be a substitute to the wood charcoal.

3.1.3 Volatile matter

The volatile matter of all briquette samples was below 30%. The highest volatile matter being 28.0% from Sample 6 (Rh50:Cc50), while Sample 1 (Rh100:Cc00) with 20.8% possesses the lowest value. Volatile matter increases with corn cob proportion impacting combustion characteristics. The changes in volatile matter might impact combustion efficiency and emissions. The average volatile matter for the samples (1-6) was 24.5% which was closer to the wood charcoal (control) with a value of 29.6% which is Sample 7. These values fell within the acceptable range for percentage volatile mater of 10% - 25% for quality briquette as stated by [15]. The briquette produced can easily ignite and burn rapidly. The briquettes produce from rice husk, sawdust and cotton stalk charcoal of [14] was also in line with the values of the moisture content obtained from the produced briquettes which ranges between 20.5% - 25.9%. The results of the volatile matter also align with findings from the studies of [13] in which the volatile matter obtained was within the range of 24.35% - 34.95%.

3.1.4 Fixed carbon content

As also depicted in figure 4.10, the highest fixed carbon content was 68.2% with compositions of (Rh100:Cc00) while the lowest was 57.7% from the ratio of Rh50:Cc50. Fixed carbon content, decreases with an increase in corn cob proportion. The changes in fixed carbon content has impact on both

combustion efficiency and emissions. On an average, the fixed carbon content for all the samples was 62.2% as compared to the wood charcoal (control) with a value of 68.5%. The high fixed carbon content indicates that the briquettes are suitable for domestic applications due to its high calorific value. This result also aligns with findings from [14] and [13] with values of 45.2% - 52.6% and 61.68% - 68.97% respectively. Also, the values of fixed carbon content obtained from this study is within the range to that acquired from the work of [16] which ranged from (11.30 – 72.07)% for briquettes produced from biochar and agricultural wastes.

3.2 Ultimate analysis

The result of ultimate analysis is shown in Table 2

Table 2: Ultimate analysis of the briquette and comparing with that of wood charcoal in gram (g)

Sample properties of the briquette	Sample ratio (RH:CC)						
	1 100:00	2 00:100	3 80:20	4 70:30	5 60:40	6 50:50	7 100
Ultimate analysis							
Hydrogen (%)	4.2	4.1	3.2	3.2	4.3	4.4	5.0
Carbon (%)	79.5	74.5	76.1	75.2	74.8	73.5	86.3
Oxygen (%)	5.6	9.1	9.0	9.5	8.8	9.6	6.7
Nitrogen (%)	1.7	1.6	1.6	1.6	1.5	1.6	1.5
Sulphur (%)	0.012	0.010	0.012	0.012	0.006	0.013	0.020

The Ultimate analysis graph determines the elemental composition of the sample ratios. The graph estimates emissions of combustion characteristics and also assesses environmental impact. The values consist of the percentages of hydrogen, carbon, oxygen, nitrogen and sulphur. The changes in elemental composition might impact combustion efficiency and emissions.

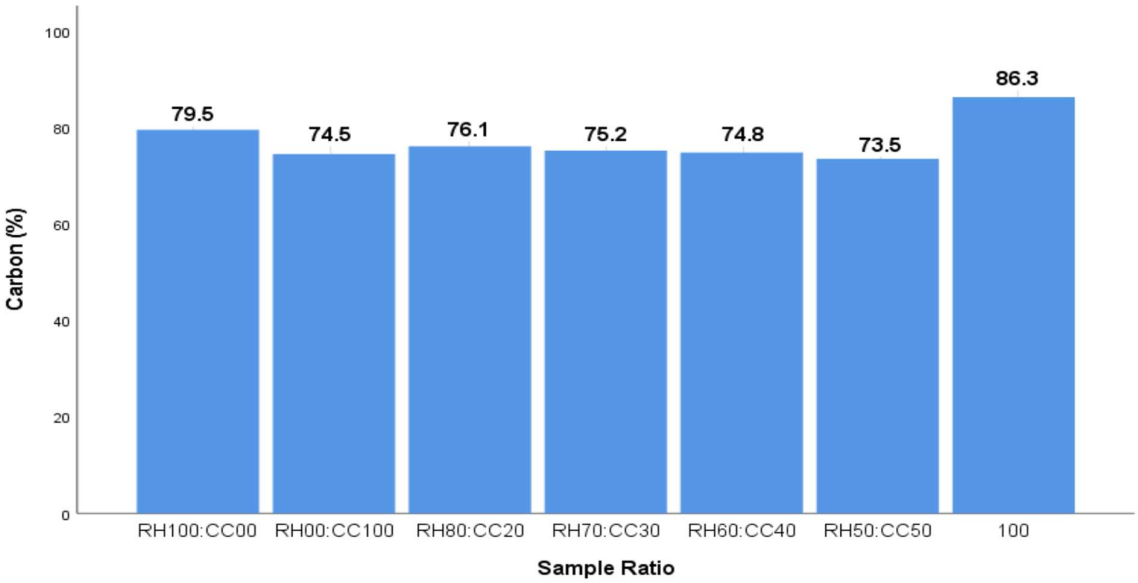


Figure 8. Effects of input variables on carbon content of the briquettes

3.2.1 Carbon

The lowest value of 73.5% was obtained from Sample 6 (Rh50:Cc50) and the highest value from Sample 1 (Rh100:Cc00) with 79.5%. Carbon decreases slightly with increasing corn cob proportion. It also indicates high energy density. The obtained values reported by [14] for rice husk alone with a carbon content of 19.07% and cotton stalk blended with rice husk with a value of 19.89% were found to be lower as compared to the experimental values of the present work. Also, [12] obtained similar values reported by [14] with values ranging from (20.80 – 29.9)% which were also higher and can produced higher emissions. The average value of carbon for all the samples was 75.6% as compared to the wood charcoal (control) with a value of 86.3%. Higher carbon content leads to more complete combusting, reducing emissions and improving air quality. Higher carbon content leads to higher density of material.

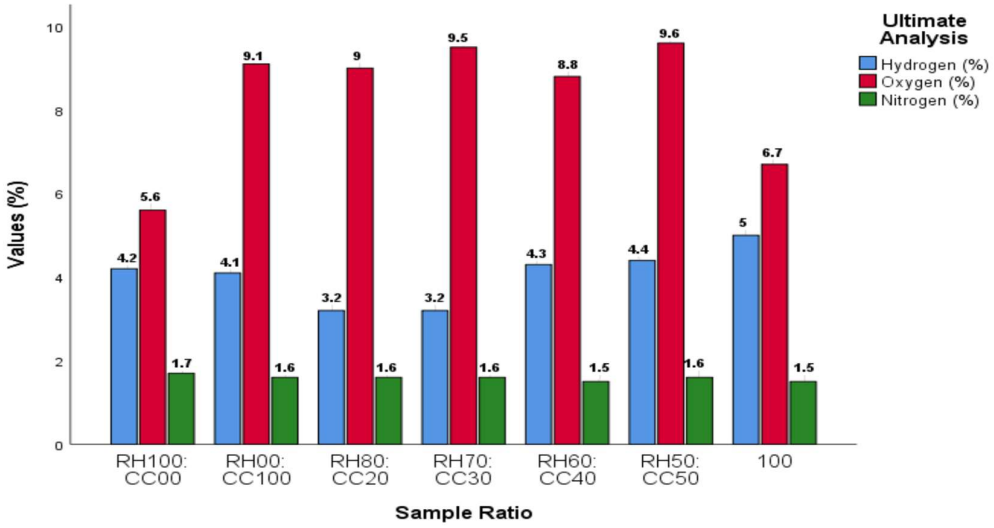


Figure 9: Effects of input variables on hydrogen, oxygen and nitrogen content of the briquettes

3.2.2 Hydrogen

The highest value of hydrogen 4.4% was obtained from Sample 6 (Rh50:Cc50), whereas the lowest value of 3.2% was from Samples 3 and 4 (Rh80:Cc20) and (Rh70:Cc30) respectively. It might impact combustion characteristics and emissions. The average value of Hydrogen for all the samples was 3.9% as compared to the wood charcoal (control) with a value of 5.0%. Values ranging from (5.13 – 6.65)% as reported by [14] are also closer to the experimental values obtained from this study. Higher hydrogen content can lead to higher energy release during combustion.

3.2.3 Oxygen

The lowest oxygen content of 5.6% was obtained from ratio of (Rh100:Cc00) and Sample 6 (Rh50:Cc50) as the highest with 9.6%. Oxygen content increases with corn cob proportion potentially impacting combustion efficiency. The values of oxygen obtained from [14] were also higher than those obtained from this research work with the values spanning from 19.07% - 19.89%. The values obtained by [12] for oxygen that ranges between 40.74 – 52.76% for briquettes produced from pet plastics and sawdust were higher to the values obtained for the present study.

3.2.4 Nitrogen

The highest value of 1.7% was from Sample 1 (Rh100:Cc00) and the lowest value from Sample 5 (Rh60:Cc40) with 1.5%. Nitrogen content remains stable throughout the experiment with value being so close. The average value of Nitrogen for all the samples was 11.2% as compared to the wood charcoal (control) with a value of 1.5%. Nitrogen values ranged between (1.22% - 16.56)% were gained from the work of [14] which were in line with the values obtained from this research work.

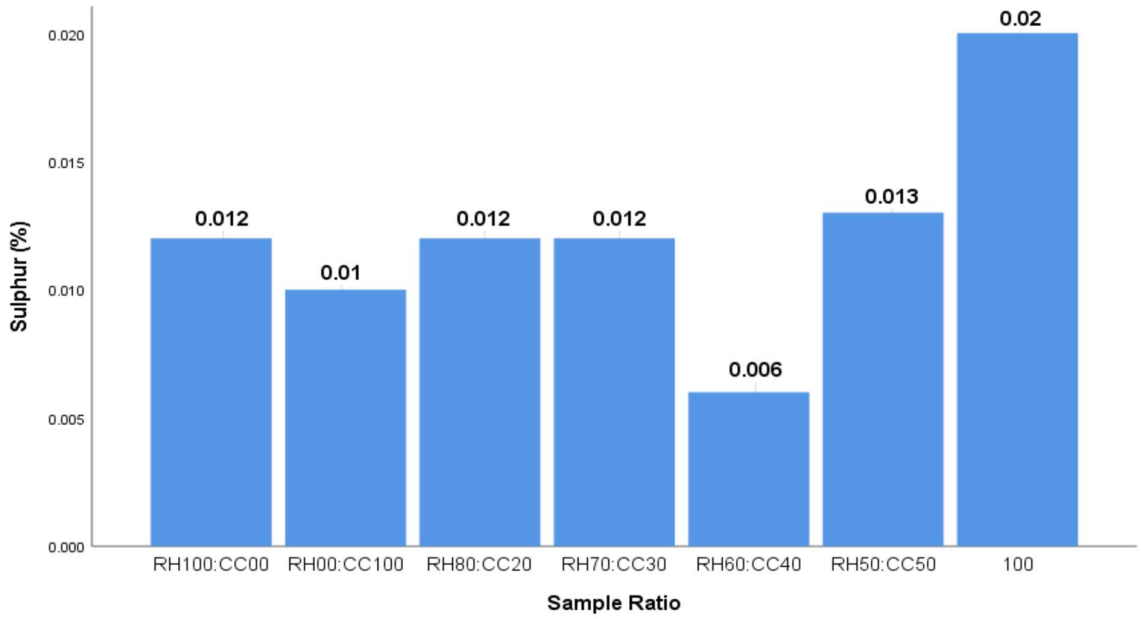


Figure 10: Effects of input variables on sulphur content of the briquettes.

3.2.5 Sulphur

The lowest value was obtained from Sample 5 (Rh60:Cc40) with 0.006%, while the highest value of 0.013% was gained at Sample 6 (Rh50:Cc50). The low sulphur content obtained across all ratios with values ranging from 0.006% - 0.013% indicating minimal variation is beneficial for reducing emissions. These values are far lower than those obtained by [16] for briquette produced from rice husk, sawdust and cotton stalk which ranges between 1.03% – 1.61% indicating that the produced briquette are safer to use since the emission of sulphur oxide will be minimal. On the other hand, the study of [12] indicated higher value of sulphur which ranges between (5.04 – 5.63) % for briquettes produced from pet plastics and sawdust. The high sulphur may lead to nitrite and sulphide emissions and this could be due to the nature of the wood waste selected for the work. The average value of sulphur for all the samples was 3.0% as compared to the wood charcoal (control) with a value of 0.020%. Sulphur can also improve fuel quality and reduce corrosion risks.

4.0 CONCLUSION

This study investigated the production and characterization of hybrid briquettes from rice husk and corn cob residues using gum Arabic as the sole binder at varying mixing ratios. Proximate and ultimate analyses were conducted to evaluate the fuel properties of the briquettes, and the results were compared with those of commercial wood charcoal. The findings demonstrate that hybrid briquettes derived from rice husk and corn cob possess desirable fuel characteristics and represent a feasible, sustainable alternative energy source for cooking and heating applications.

The results confirm that the utilization of agricultural residues for briquette production can significantly reduce dependence on fuel wood, thereby mitigating deforestation and environmental degradation. Among the various blending ratios evaluated, the rice husk: corn cob blend of 80:20 (RH80:CC20) exhibited particularly promising performance, offering a favourable balance of energy density, compressive strength, and durability. Although the hybrid briquettes did not outperform commercial wood charcoal in terms of burning and boiling times, their environmental benefits, renewability, and sustainability position them as viable alternatives to conventional fuels.

Overall, this study highlights the significant potential of converting agricultural waste into solid biofuels for enhancing energy security, promoting environmental management, and supporting rural economic development in Nigeria. The adoption of hybrid briquettes as an alternative cooking fuel offers a cost-effective, environmentally friendly, and sustainable pathway toward reducing reliance on fossil fuels and traditional biomass, thereby contributing to the global quest for renewable energy solutions.

Recommendations

Production of hybrid briquettes of rice husk and corn cob need to be encouraged as it serves as an alternative to wood charcoal as fuel. There is need to investigate other rice husk: corn cob ratios or additives to improve combustion properties and energy output in order to have more valuable results. Thorough assessment of the environmental impact of rice husk: corn cob briquettes including emissions and ash disposal. In all the analyses carried out from this research work, wood charcoal being the control had more positive attributes when compared to hybrid briquette. In light of this, other agricultural residues need to be briquetted with a view of replacing wood charcoal as a source of fuel for cooking.

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