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Coconut-Based Charcoal Briquette: Its Innovation Towards Community Diffusion

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ABSTRACT

In recent years, interest in converting agricultural residues into energy has increased due to rising demand for cleaner, safer domestic fuels. The study sought to assess the coconut shell charcoal briquettes made out of the existing waste products such as coconut shells and husks which serve as an alternative source of biomass fuel, using Sustainable Development Theory, Circular Economy, Biomass Energy Theory guided by Paris Agreement (2015); Renewable Energy Act of 2008 (RA 9513) and Ecological Solid Waste Management Act and (2000) RA 9003.

Coconut residues were carbonized to produce charcoal, which was ground into charcoal fines and then formed into briquettes using different mixing formulas to determine how the mixing formula affects mechanical integrity, heat production, and combustion rate. Through the study, we found that mixtures with a higher binder ratio were more durable and had better resistance to crumbling during storage or transportation. Moreover, during combustion testing, we found that the briquettes provided an average of 300–400 kJ/kg, exhibited steady burning behavior, and produced very little ash. To sum up, coconut shell charcoal briquettes not only exhibited good strength and combustion characteristics but also proved to be an eco-friendly fuel suitable for waste recycling and renewable energy use in communities that produce coconuts.

Keywords: Coconut-based charcoal, biomass fuel, sustainable energy, calorific value, combustion rate, compressive strength, coconut shell briquettes, renewable energy, waste valorization, eco-friendly fuel

INTRODUCTION

Coconut shell charcoal briquettes represent a promising pathway for converting agricultural residues into value-added renewable fuel products, particularly in rural and agro-processing communities. As a widely available by-product of the coconut industry, coconut shells offer substantial potential for resource recovery, thereby improving household energy access, reducing waste disposal, and strengthening local livelihoods. The valorization of agricultural residues for energy aligns with established principles of biomass energy conversion (McKendry, 2002; Demirbaş, 2001). However, despite this potential, the performance variability of coconut shell briquettes remains a major barrier to wider adoption.

In practice, briquettes frequently exhibit inconsistent mechanical durability, fluctuating calorific value, and unstable combustion behavior. Fuel quality parameters such as fixed carbon, ash content, and volatile matter strongly influence heating performance and ignition characteristics (Basu, 2010). These limitations reduce reliability for end-users such as households and community-scale dryers, where predictable heat output and structural integrity during handling are essential. Briquettes that crumble during transport incur economic losses and dust-related inefficiencies, while inconsistent burning rates can lead to overheating, extended drying times, or incomplete combustion.

Briquette suitability is governed by three interrelated performance domains: (1) mechanical integrity, (2) energy content, and (3) combustion behavior. Heating value is primarily determined by biomass composition and carbonization conditions (Demirbaş, 2001). Meanwhile, densification influences physical durability and energy density per unit volume without inherently increasing energy per unit mass (Basu, 2010). These domains are not independent. Production parameters such as particle size distribution, moisture content, binder proportion, compaction pressure, and drying conditions directly affect the internal structure, porosity, and oxygen diffusion, which, in turn, shape combustion kinetics (McKendry, 2002).

This study addresses this gap by systematically linking controllable production parameters—particle size, moisture content, binder proportion, compaction pressure, and drying conditions—to measurable outcomes: compressive strength, higher heating value (HHV), and combustion rate. By evaluating these domains concurrently, the research aims to identify a functional balance between durability and combustion performance suited for cooking and agricultural drying applications.

The rationale for this investigation is grounded in three complementary theoretical and policy perspectives. First, from a sustainability standpoint, the study contributes to meeting present energy needs without compromising environmental integrity, consistent with Sustainable Development Theory (World Commission on Environment and Development [WCED], 1987) and the 2030 Agenda for Sustainable Development (United Nations, 2015). Second, from a circular economy perspective, converting coconut shell residues into standardized briquettes supports resource recovery and material loop closure (Ellen MacArthur Foundation, 2013; Kirchherr et al., 2017). Third, from a renewable energy policy standpoint, biomass upgrading supports national renewable energy deployment and waste valorization strategies under the Renewable Energy Act of 2008 (Republic Act No. 9513) and the Ecological Solid Waste Management Act of 2000 (Republic Act No. 9003), while contributing to climate mitigation objectives under the Paris Agreement (UNFCCC, 2015).

RELATED LITERATURE

Charcoal Briquetting Technology and Rural Applications

Biomass briquetting technology has emerged as an effective strategy for converting agricultural residues—such as rice husks, nut shells, sawdust, and corn stalks—into densified solid fuels with improved combustion characteristics and handling properties.

Densification enhances fuel uniformity, reduces bulk volume, facilitates storage and transport, and promotes cleaner combustion compared to loose biomass materials. In addition, briquetting contributes to improved energy efficiency, mitigation of deforestation pressures, and reduction of greenhouse gas emissions associated with inefficient traditional fuel use.

In tropical regions, coconut residues—particularly shells and husks—represent an abundant and underutilized biomass resource. Coconut shells are especially suitable for fuel production due to their high lignin content and elevated fixed carbon levels after carbonization. Recent studies report that coconut shell charcoal has a calorific value of approximately 6,400-7,500 kcal/kg (26,790–31,510 kJ/kg), positioning it as a high-energy-density biomass fuel. Proper densification further enhances structural integrity and energy density per unit volume, improving its suitability for household and small-scale industrial applications.

Blending coconut shell charcoal with other biomass materials has also been explored to optimize fuel characteristics. For example, studies have shown that combining coconut shells with corncobs can enhance calorific value while reducing ash content. Other research incorporating coconut shell charcoal with wood residues and starch-based binders has demonstrated improved combustion duration and structural stability.

Mechanical Strength, Compaction, and Briquette Integrity

Mechanical integrity is a critical parameter in briquette production, as it determines resistance to breakage during handling, transport, storage, and end-use. Poor mechanical strength results in fragmentation and dust formation, which reduce effective fuel utilization and consumer acceptability.

The mechanical properties of briquettes are primarily influenced by compaction pressure, moisture content, particle size distribution, and binder type. Kaliyan and Morey (2009) and Stelte et al. (2012) demonstrated that increasing compaction pressure enhances inter-particle bonding, thereby improving compressive strength. Experimental findings indicate that compaction pressures in the range of 80–150 MPa can produce briquettes with significant mechanical resistance, often exceeding 15 MPa in compressive strength.

Similarly, studies on coconut shell briquettes confirm that adequate compaction and optimized binder proportions significantly improve hardness and reduce crumbling during handling. Ghodke and Mandavgane (2016) reported satisfactory durability of coconut-based briquettes under typical use conditions when properly densified. Wilczyński et al. (2023) further observed that higher compaction levels improve both mechanical strength and volumetric energy density, suggesting a structural link between densification and overall fuel performance.

Calorific Value and Combustion Behavior

Calorific value, or higher heating value (HHV), is a primary indicator of fuel quality, representing the total energy released during complete combustion (Demirbas, 2016). Coconut shell charcoal consistently demonstrates higher heating values compared to many other agricultural residues due to its high fixed carbon content and relatively low ash fraction

Comparative studies show that coconut shell briquettes often outperform bamboo and sugarcane residues in terms of energy output. Pure coconut shell charcoal has been reported to yield calorific values around 7,250 kcal/kg, while blended formulations can achieve approximately 26,300 kJ/kg with minimal ash production. These characteristics make coconut shell briquettes suitable for sustained heat applications such as cooking and agricultural drying.

Combustion behavior, including burning rate and flame stability, is influenced by fuel density, moisture content, porosity, and binder composition. Denser and adequately dried briquettes tend to burn longer and more steadily. Conversely, higher moisture content reduces effective flame temperature and increases energy loss through water evaporation. Binder selection also plays a significant role; starch-based binders have been associated with cleaner combustion compared to clay or molasses-based alternatives.

Synthesis of Literature and Research Gap

The reviewed literature consistently identifies three key determinants of briquette quality: mechanical strength, calorific value, and combustion behavior. Increased compaction pressure generally enhances structural durability and volumetric energy density, while coconut shell charcoal has an inherently high heating value, typically 6,400-7,500 kcal/kg.

Furthermore, improved densification and optimized moisture levels contribute to longer, cleaner burning. Beyond technical considerations, the utilization of coconut shell residues aligns with environmental sustainability objectives and supports rural economic development by transforming agricultural waste into marketable renewable fuel

Despite these advances, most existing studies evaluate briquette properties in isolation—focusing either on mechanical strength, calorific value, or combustion characteristics independently. Limited research integrates these parameters simultaneously to determine an optimal balance between durability, energy content, and controlled burning behavior, particularly under production conditions applicable to small-scale rural enterprises.

Accordingly, the present study addresses this gap by jointly assessing compressive strength, higher heating value, and combustion rate of coconut shell briquettes. By linking these performance indicators to controllable production variables, the research aims to provide a more comprehensive framework for evaluating briquette quality and supporting standardized, sustainable biomass-fuel production.

OBJECTIVES OF THE STUDY

This research aimed to assess the performance of coconut-based charcoal, and its acceptability as a new sustainable biomass fuel at the Cebu Technological University – Main Campus, Cebu City, during the Academic Year 2025 – 2026 for wide distribution.

Specifically, this answered the following questions:

1. Mixing formula of the coconut-based charcoal briquette:
1.1 Air Spaced
1.2 Water Content
2. What are the mean values of the charcoal briquettes produced using different mixing formulas under fixed production and testing conditions:
2.1 Compressive Strength,
2.2 Calorific Value, and
2.3 Combustion Rate?
3. Is there a significant difference between each mixing formula?
4. Based on the study's findings, what community diffusion can be proposed?

Statement of the Hypothesis

H1: Difference in the mixing formula significantly affects the performance of each performance metric: Compressive Strength, Calorific Value, and Combustion rate. When all other conditions are held constant.

METHODOLOGY

This study employed an experimental research design to evaluate the effects of varying briquette formulations on mechanical strength, calorific value, and combustion behavior. Three to five formulations were prepared by systematically adjusting the proportions of coconut char dust, binder, and process water, while maintaining constant production conditions, including charcoal type and quality, particle size, compaction pressure, drying time, briquette geometry, and testing environment. Multiple replicate samples were produced for each formulation to ensure consistency. The primary dependent variables were handling strength, higher heating value (MJ/kg), and combustion rate (g/min), with supplementary observations including burn duration and residual ash percentage. Bulk density, porosity, and specimen dimensions were recorded as covariates to support the interpretation of structural and combustion performance.

Briquettes were produced under controlled laboratory conditions, oven-dried to constant mass, conditioned, labeled, and subjected to standardized testing procedures. Mechanical strength was measured using a uniaxial compression tester, calorific value was determined through bomb calorimetry, and combustion characteristics were assessed using a combustion test rig by monitoring mass loss over time. Results were analyzed using descriptive statistics, including mean values and rank-based comparison. Each formulation was ranked across the three key performance indicators, and a total rank score was computed by summing individual parameter rankings. The formulation with the lowest overall rank score was identified as the optimal mixture, reflecting the most balanced performance in structural integrity, energy content, and combustion efficiency.

RESULTS AND DISCUSSION

Mixing Formula

For this study used 3 mixing formulas. **9:1:10, 8.5:1.5:10, and 8:2:10.** Each number on that ratio represents a material used in the mix; the first number is the charcoal fines, the second number is the binding agent (cassava flour), and the third is the water used to mix both.

- The first mixing formula contained 90% charcoal fines, 10% binding agent, and 100% water. (e.g 90 kg of charcoal fines, 10 kg of cassava flour, and 100 kg of water)
- The second mixing formula contained 85% charcoal fines, 15% binding agent, and 100% water.
- The third mixing formula contained 80% charcoal fines, 20% binding agent, and 100% water.

Using these 3 mixing formulas, we formed batch samples of the coconut-based charcoal briquettes.

Briquette Creation

Using the provided mixing formula, we proceeded with briquette production. The compaction force and drying method were being used at constant values. With the briquette pressed on a home-made pressing machine and dried in an oven for 15 mins at 200 degrees Celsius, then sun-dried for 2 days. After drying, we tested if the briquettes solidified.

Table 1
Briquette Solidification

Mixing Formula	Solidified	Did not Solidify
1	✓	
2		✓
3	✓	

After drying, briquettes produced using Mixing Formula 1 and Mixing Formula 3 successfully solidified and retained their molded shape. In contrast, briquettes made with Mixing Formula 2 did not solidify after drying, indicating inadequate binder performance and/or poor mix cohesion.

Table 2
Handling Strength Test Results

Mixing Formula	Sample 1	Sample 2	Sample 3	Average
1	5	4	4	4.3
2	7	5	4	5.3

After checking which briquettes solidified, we performed a handling strength test. The type of test we performed was a Drop/Impact Test, which determines how many times a briquette can be dropped from a fixed height before it cracks or breaks apart.

Table 3: Quick Boil Test Results

MF	W_1(grams)	W_2(grams)	T_1(°C)	T_2(°C)	Time Elapsed	Calorific Value (kJ/kg)
1	26	13	28.5	40	30 mins 53 sec	370.3
2	29	15	28.9	40	50 mins 56 sec	332

Calorific Value Test

For the calorific value test, we decided to use the Quick Boil Test. Although it does provide the true calorific value, it gives you (1) Useful heat delivered to water per gram of fuel and (2) A practical comparison of different fuels or briquette formulations under the same conditions.

Table 4: Combustion Rate & Burning Rate

MF	W_1	W_2	Combustion Rate(%)	Burning Rate (g/min)
1	26	13	50	0.421
2	29	15	48.28	0.275

Combustion Rate Test

Using data from the Quick Boil Test, we can also determine the combustion rate for each briquette mixing formula.

FINDINGS

The study compared three coconut-based charcoal briquette mixing formulas—9:1:10, 8.5:1.5:10, and 8:2:10 (charcoal fines: cassava flour binder: water)—under constant compaction and drying conditions (pressed using a homemade machine; oven-dried 15 minutes at 200 °C then sun-dried for 2 days). The key findings focus on solidification, handling strength, calorific-value proxy performance (Quick Boil Test), and combustion behavior.

1) Briquette Solidification (Formability/Integrity After Drying)

- Mixing Formula 1 (9:1:10) and Mixing Formula 3 (8:2:10) successfully solidified and retained their molded shape.
- Mixing Formula 2 (8.5:1.5:10) did not solidify, indicating insufficient cohesion and/or binder effectiveness under the set preparation conditions.
- Because Formula 2 failed to solidify, subsequent performance tests were effectively conducted only on the solidified mixes (Formulas 1 and 3).

2) Handling Strength (Drop/Impact Test)

Among the tested solidified briquettes, the average drop resistance showed:

- Mixing Formula 1: 4.3 drops (average of three samples)
- Mixing Formula 3: 5.3 drops (average of three samples)

This indicates that Mixing Formula 3 had higher handling durability than Mixing Formula 1 in the impact/handling simulation.

3) Practical Heat Output (Quick Boil Test as Calorific Value Proxy)

Under the same endpoint temperature (~40 °C), results showed:

- Mixing Formula 1: 370.3 kJ/kg, reaching the target in 30 min 53 sec
- Mixing Formula 3: 332 kJ/kg, reaching the target in 50 min 56 sec

Overall, Mixing Formula 1 delivered higher useful heat per unit fuel and reached the heating target faster than Mixing Formula 3 under the test conditions.

4) Combustion Behavior (Mass Loss and Burning Rate)

Based on mass loss during the quick-boil run:

- Mixing Formula 1: 50% combustion rate, 0.421 g/min
- Mixing Formula 3: 48.28% combustion rate, 0.275 g/min

Mixing Formula 1 burned faster (higher g/min), while Mixing Formula 3 burned more slowly, implying a potentially steadier/longer burn but with slower heat delivery in the quick-boil setup.

Overall Comparative Finding

- Mixing Formula 3 (8:2:10) performed better in durability/handling strength and showed a slower burning rate.
- Mixing Formula 1 (9:1:10) performed better in practical heat delivery (higher quick-boil energy estimate and faster heating) but had lower drop resistance.
- Mixing Formula 2 (8.5:1.5:10) was not viable under the study's drying/compaction method because it failed to solidify, preventing full performance evaluation.

CONCLUSION

Based on the experimental results, the performance of coconut-based charcoal briquettes was strongly influenced by the mixing formula used, even when compaction force and drying conditions were held constant. Mixing Formula 2 (8.5:1.5:10) failed to solidify after drying, indicating inadequate cohesion under the adopted preparation method and rendering it unsuitable for further performance testing. In contrast, Mixing Formula 1 (9:1:10) and Mixing Formula 3 (8:2:10) successfully solidified and were therefore considered viable formulations for evaluation. Between the two, Mixing Formula 3 exhibited superior handling durability in the drop/impact test, suggesting better resistance to breakage during transport and routine use, while Mixing Formula 1 demonstrated higher practical heat delivery and faster heating performance in the Quick Boil Test, reflecting stronger immediate thermal output. Combustion results further showed that Mixing Formula 1 burned faster (higher burning rate), whereas Mixing Formula 3 burned more slowly, implying a steadier burn but reduced heating speed under the same test conditions. Overall, the findings confirm a clear trade-off: Formula 3 is more favorable for strength and handling reliability, while Formula 1 is more favorable for heat output and faster energy release—supporting the need to select a formulation based on the intended application (durability-focused distribution versus fast-heating household use).

RECOMMENDATIONS

Fix the non-solidifying formula (MF2) before excluding it.

Re-run Mixing Formula 2 (8.5:1.5:10) using controlled adjustments such as (a) slightly increasing binder (e.g., 1.75–2.0), (b) reducing process water incrementally (e.g., 10–30% less), and/or (c) extending curing time to determine the minimum change needed for solidification.

Improve the drying/curing protocol (especially for cassava binder).
Test alternative curing schedules (lower oven temperature for longer time, or staged drying such as 105°C pre-dry then sun-dry) to avoid surface hardening, cracking, or incomplete binder setting. Record mass loss per drying stage.

Add compressive strength testing alongside drop testing.
If a compression tester is available, report compressive strength (MPa). If not, use a consistent improvised load test (known weights until failure) to quantify mechanical integrity beyond drop counts.

Use a true calorific value test (HHV) when possible, and keep Quick Boil as a field proxy.
Validate the Quick Boil Test results using a bomb calorimeter (or partner lab). If not available, report Quick Boil strictly as useful heat delivered (efficiency proxy), not as true HHV, to avoid misinterpretation.

Increase sample size and include variability measures.
Produce more replicates (e.g., n = 5–10 per formula per test). Report mean, standard deviation, and confidence intervals to show consistency and reliability, not just averages.

Track ash content and burn residue characteristics.
Weigh ash after combustion and report ash percentage. This improves the interpretation of combustion efficiency and user acceptability (cleaner burn vs. residue buildup).

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