The International Review of Multidisciplinary Research
Volume 1, Issue 3, March 2026, pp. 617-635
https://doi.org/10.5281/zenodo.19355947

Co-Briquetting of Cassava Peels and Paper Waste: Enhancing Fuel Efficiency and Reducing Emission in Alternative Biomass Fuels

Michael James E. Paracuelles [1], Angel Marie V. Florentino [2], Sophyia Lei M. Cohitmingao [3], Kristie Apple R. Perez [4], Sharmaine Kim E. Marabulas [5], Adrian M. Abarquez [6], Rhino Rienz L. Casas [7], Nathalie Faith P. Matugas [8]
Maguikay National High School
[1] mchlxx1200@gmail.com, [2] kuriangel3572@gmail.com, [3] csophyia@gmail.com,
[4]kristieappleperez@gmail.com, [5] sharmaine.kim.marabulas@gmail.com, [6] adrian.abarquez@deped.gov.ph,
[7] rhinorienz.casas@deped.gov.ph, [8] nathaliefaith.matugas@deped.gov.ph

Article Details:

Received: 06 March 2026
Revised: 14 March 2026
Accepted: 23 March 2026
Published: 31 March 2026
Corresponding Email:
adrian.abarquez@deped.gov.ph

Recommended Citation:

Paracuelles, M. J. E., Florentino, A. M. V., Cohitmingao, S. L. M., Perez, K. A. R., Marabulas, S. K. E., Abarquez, A. M., Casas, R. R. L., Matugas, N. F. P. (2026). Co-Briquetting of Cassava Peels and Paper Waste: Enhancing Fuel Efficiency and Reducing Emission in Alternative Biomass Fuels. The International Review of Multidisciplinary Research. 1 (3), 617-635.
https://doi.org/10.5281/zenodo.19355947

Index Terms:

cassava peels, co-briquetting, biomass fuel, emissions

Abstract. Cassava peels are a by-product of Manihot esculenta, commonly known as the “bread of the tropics,” and are produced in large quantities during root processing but are often discarded as waste. Similarly, paper waste includes discarded materials such as newspapers, packaging, notebooks, and office documents that frequently accumulate in landfills and contribute to environmental pollution. Due to increasing concerns about improper waste disposal and the depletion of fossil fuels, these materials are being explored as potential resources for alternative biomass fuel production. This study aimed to evaluate the fuel characteristics and overall performance of briquettes produced through the co-briquetting of cassava peels and paper waste as a sustainable alternative fuel. The study utilized a true experimental research design under the quantitative approach and was conducted at a residence in Barangay Maguikay, Mandaue City, Cebu. Briquettes were produced using different cassava peel and paper waste ratios and were tested to determine key fuel properties, including moisture content, density, heat output, ash content, combustion time, ignition time, and shatter resistance. One-way analysis of variance (ANOVA) was applied to determine significant differences among the experimental setups. The findings revealed that Setup D exhibited the highest mean moisture content at 289.49%, indicating a high water-to-biomass ratio. The results also showed that varying the proportions of cassava peels and paper waste significantly affected the fuel properties of the briquettes. Among the experimental setups, Setup C demonstrated the most balanced performance, while the commercial briquette remained superior in density and consistency. Overall, the study highlights the potential of co-briquetting cassava peels and paper waste as a renewable biomass fuel alternative.

Introduction

Cassava peels are a byproduct of Manihot esculenta, commonly known as the "bread of the tropics." They are produced in large quantities during root processing and are often discarded as waste. Cassava peels are a significant agricultural byproduct, often considered waste, yet they contain valuable components for various applications (Mbamalu & Mohammed, 2024). On the other hand, paper waste includes discarded materials such as newspapers, packaging, and office documents that often end up in landfills. According to Abushammala et al. (2023), paper is primarily made from wood-based cellulose pulp, and its production contributes to environmental issues like pollution and deforestation. With growing environmental concerns, both cassava and paper waste are now being explored as sustainable resources in alternative fuel development.

On the other hand, paper waste includes discarded paper materials like newspapers, packaging, and office documents that often end up in landfills. Fuel efficiency and emissions reduction aim to maximize energy output while minimizing pollutants. According to Arachchige (2021), fuel efficiency is implicitly addressed by the alarming rate of fossil fuel depletion and the environmental concerns stemming from their use, which directly link fossil fuel combustion to increased atmospheric greenhouse gas concentrations. Petroleum, coal, and oil are identified as direct contributors to greenhouse gas emissions and global warming. In contrast, renewable energy sources offer a sustainable alternative due to their lower environmental impact, highlighting a global effort to mitigate emissions and improve

Researchers have empirically observed significant waste issues in Cebu, with Cebu City spending over ₱ 407 million on waste disposal in 2024 due to poor segregation and inadequate facilities, as flagged by the Commission on Audit (Mascardo, 2025). Paper waste alone accounts for approximately 4.8% of garbage collected in Cebu City (Magsumbol, 2021). Proactive measures are being taken, with Mandaue City's Department of Education successfully converting paper waste into sellable charcoal (Virador, 2024). Concurrently, cassava production is substantial in Cebu, accounting for 31.11% of major vegetables and root crops in the first half of 2024 (psa.gov.ph, 2023), prompting Mandaue City to explore converting food waste, including cassava peels, into new resources with Japanese partners (Desiderio, 2024). These efforts highlight the potential to combine paper and cassava waste to create novel fuel sources, advancing Cebu's move towards a sustainable, circular economy.

Internationally, a study by Yu et al. (2022) investigated factors affecting the production and use of biomass sawdust briquettes in Madagascar, combining SWOT analysis with the Analytic Hierarchy Process (AHP). This research was driven by the need of developing nations for affordable, accessible renewable energy, especially given the environmental impact of fossil fuels and Madagascar's abundant sawdust waste. The findings revealed critical hindrances, including limited public awareness, inadequate government support, political instability, challenges to societal acceptance, greater focus on other renewables, and existing fossil-fuel incentives. It concludes that promoting sawdust briquettes will require strategies such as financial subsidies and tax breaks.

Nationally, a study by Genuino et al. (2022) examined the use of bio-briquettes to address environmental and health issues arising from food waste and coal combustion. Using banana and orange peels as base materials, and sawdust as a control, the researchers tested paper pulp and cassava starch as binders. They evaluated the briquettes on density, burning rate, ignition time, and efficiency. The findings showed that sawdust with a cassava binder performed best for ignition and overall efficiency. In contrast, banana briquettes with a paper binder had the slowest burning rate, highlighting the potential of different production methods.

A significant gap exists in the study of co-briquetting. Despite their individual potential, the combined use of abundant waste streams, such as cassava peels and paper waste, remains underexplored. This is particularly evident in the lack of localized research in areas such as Mandaue City. There is a particular scarcity of data on how different mixing ratios affect critical fuel properties such as combustion efficiency and emissions. In addition, limited studies have examined how binder proportion, moisture content, and design factors, such as hole presence, influence the performance of co-briquettes in terms of density, heat output, ash content, combustion time, ignition time, and shatter resistance. This research aims to address these deficiencies by providing a localized investigation using accessible, small-scale briquetting methods. By testing the performance of co-briquettes made from these materials, this study seeks to fill this critical gap and provide valuable data for the development of sustainable energy solutions in our community.

Thus, this study aimed to conduct an experimental investigation into the performance of co-briquettes. The overall purpose of this study was to create an affordable and eco-friendly alternative fuel from agricultural and paper waste, thereby supporting Sustainable Development Goals 11 (Sustainable Cities and Communities), 9 (Industry, Innovation and Infrastructure), and 7 (Affordable and Clean Energy).

Theoretical Background

Guided by Reed and Bryant's Densification Theory (1978) and Turns' Combustion Theory (1996), this study conceptualizes the development of biomass briquettes as an integrated renewable energy solution aligned with Sustainable Development Goals (SDGs) 7, 9, and 11. Densification theory provides the foundational framework for transforming loose agricultural and paper waste into compact, energy-dense briquettes, thereby enhancing fuel handling, storage efficiency, and combustion consistency.

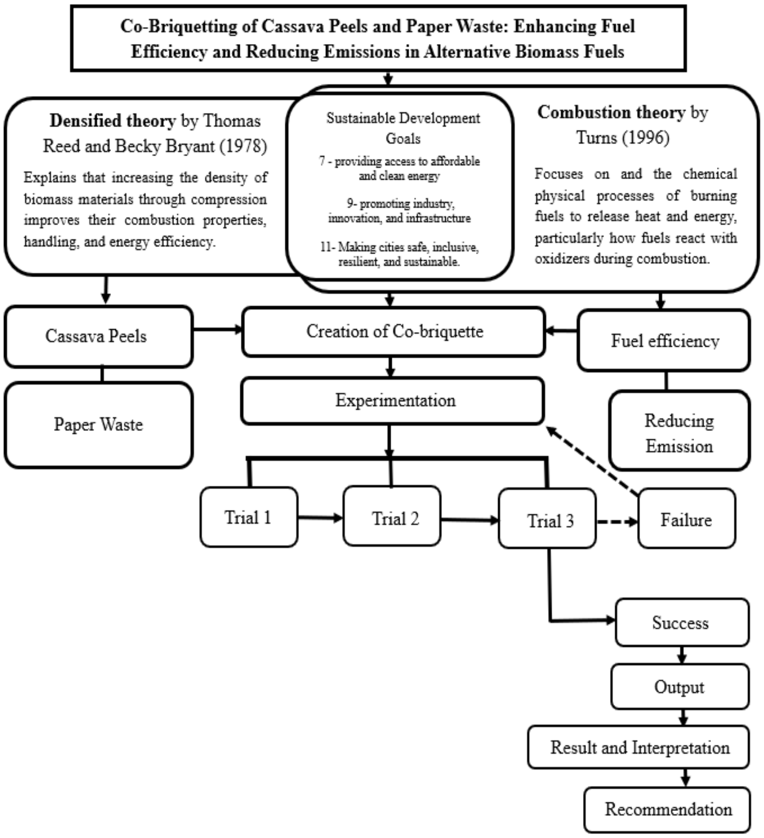

Figure 1: Schematic diagram of co-briquette cassava peels and paper waste for fuel efficiency and reduced emission.

Statement of the Problem

This study investigated the potential of co-briquetting cassava peels and paper waste using tailored briquette molding as an alternative biomass fuel in Mandaue City, Cebu, S.Y. 2025–2026. The findings of this study served as a basis for recommending sustainable practices in alternative fuel production.

Specifically, this study answered the following questions:

1. What is the moisture content of the following setups:
    - 1.1 400g (80%) cassava peels, 100g (20%) paper waste;
    - 1.2 350g (70%) cassava peels, 150g (30%) paper waste;
    - 1.3 250g (50%) cassava peels, 250g (50%) paper waste;
    - 1.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    - 1.5 commercial briquettes?

2. Is there a significant difference in the mean moisture content of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

3. What is the density of the following setups:

    - 3.1 400g (80%) cassava peels, 100g (20%) paper waste;
    - 3.2 350g (70%) cassava peels, 150g (30%) paper waste;
    - 3.3 250g (50%) cassava peels, 250g (50%) paper waste;
    - 3.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    - 3.5 commercial briquettes?

4. Is there a significant difference in the mean density of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

5. What is the heat output of the following setups:

    5.1 400g (80%) cassava peels, 100g (20%) paper waste;
    5.2 350g (70%) cassava peels, 150g (30%) paper waste;
    5.3 250g (50%) cassava peels, 250g (50%) paper waste;
    5.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    5.5 commercial briquettes?

6. Is there a significant difference in the mean heat output of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

7. What is the ash content of different setups:

    7.1 400g (80%) cassava peels, 100g (20%) paper waste;
    7.2 350g (70%) cassava peels, 150g (30%) paper waste;
    7.3 250g (50%) cassava peels, 250g (50%) paper waste;
    7.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    7.5 commercial briquettes?

8. Is there a significant difference in the mean ash content of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

9. What is the combustion time of different setups:
    9.1 400g (80%) cassava peels, 100g (20%) paper waste;
    9.2 350g (70%) cassava peels, 150g (30%) paper waste;
    9.3 250g (50%) cassava peels, 250g (50%) paper waste;
    9.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    9.5 commercial briquettes?

10. Is there a significant difference in the mean combustion time of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

11. What are the ignition times of different setups:
    11.1 400g (80%) cassava peels, 100g (20%) paper waste;
    11.2 350g (70%) cassava peels, 150g (30%) paper waste;
    11.3 250g (50%) cassava peels, 250g (50%) paper waste;
    11.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    11.5 Commercial briquettes?

12. Is there a significant difference in the mean ignition time of briquettes produced from different cassava peel–paper waste ratios and commercial briquettes?

13. What is the shatter resistance of different setups:
    13.1 400g (80%) cassava peels, 100g (20%) paper waste;
    13.2 350g (70%) cassava peels, 150g (30%) paper waste;
    13.3 250g (50%) cassava peels, 250g (50%) paper waste;
    13.4 300g (60%) cassava peels, 200g (40%) paper waste; and
    13.5 commercial briquettes?

14. Which briquette setup demonstrates the best overall performance in terms of moisture content, density, heat output, ash content, combustion time, ignition time, and shatter resistance?

15. Based on the results, what recommendations might be proposed

Methodology

Research Design

The study employed a true experimental research design within the quantitative approach. To investigate the co-briquetting of cassava peels and paper waste for improved fuel efficiency and reduced emissions, establish cause-and-effect relationships by manipulating independent variables and observing their effects on dependent variables (Zubair, 2020). Specifically, a Factorial Experiment in a Randomized Complete Block Design (RCBD) was applied, allowing multiple factors to be tested simultaneously while minimizing variability among groups through blocking, ensuring fair comparisons and reducing experimental error (Allam, 2025). By integrating a true experimental design with a factorial RCBD approach, the study provided a rigorous framework for systematically evaluating the combined effect of cassava peels and paper waste as an alternative biomass fuel.

Research Environment

The study was conducted at a residence located in 7D, M.D. Echavez Street, Villa Fatima Sudlon, in Barangay Maguikay, Mandaue City, Cebu. This specific location was chosen for two primary reasons essential to the researchers' study. First, the site provided a spacious and open area, which was critical for ensuring the safety of the researchers and the surrounding community. The process of creating and testing briquettes involved flammable materials, making a secure, open space a requirement. This open area also served as a suitable and convenient location for naturally drying the co-briquettes made from cassava peels and paper waste. Furthermore, the location offered logistical advantages crucial to the project's execution, as it allowed the researchers to maintain convenience and private access to the work area without disturbing others and provided a secure space to store all materials and the finished briquettes throughout the duration of the study.

Research Materials and Equipment

The study used cassava peels as the primary biomass material and paper waste as an additional combustible component. Cassava starch and tap water served as natural binders for the mixture. Tools such as a blender, knife, grater, paper shredder, buckets, and spatula were used to process and mix the materials, while a briquetting mold shaped the briquettes. Drying racks or trays were used for sun-drying. Measurement instruments including a weighing scale, ruler, caliper, calculator, graduated cylinder, and multimeter were used to measure mass, dimensions, density, and resistance. For combustion testing, a charcoal stove, matchsticks, stainless steel tray, thermocouple thermometer, and digital stopwatch were used to ignite the briquettes, measure heat output, record burning time, and collect ash. Commercial briquettes were used for comparison, while plastic gloves, surgical masks, a notebook, and a pen ensured safety and proper data recording.

Research Procedures

The researchers used appropriate personal protective equipment (PPE) to prevent potential accidents and ensured safety during the experimentation. All researchers wore appropriate personal protective equipment, including surgical face masks and gloves, throughout the process. Testing of co-briquettes made from cassava peels and paper waste was conducted in a safe, controlled environment, ensuring that any gas emitted did not harm the researchers or individuals nearby.

Preparation of Materials

The researchers obtained the necessary materials for the experiment from several sources. First, cassava was obtained from a neighboring farm owned by an associate of one of the researchers. Second, paper waste was collected from Maguikay National High School, including office papers, newspapers, and scrap paper. Lastly, additional tools and equipment were purchased from local markets and malls within Mandaue and Cebu. At the same time, other required items were secured through online suppliers to ensure adequacy and appropriateness for the experimental procedures.

Experimental Procedures

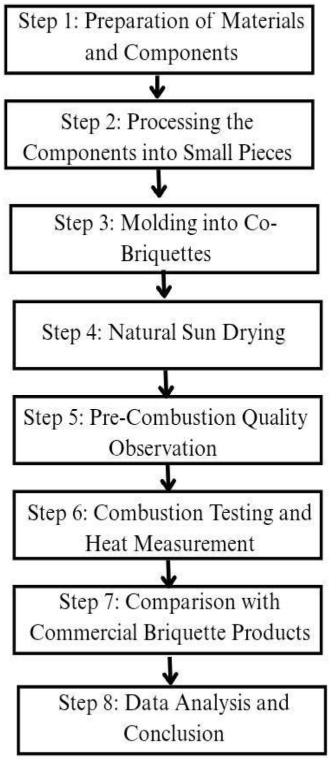

Figure 2: Diagram of the Experimental Process for Co-Briquetting Cassava Peels and Paper Waste.

Step 1: Preparation of Components and Materials

The researchers prepared 500 g of cassava peels and 500 g of paper waste as the main materials. Additionally, 10 g of cassava starch and 150 mL of water were prepared for the co-briquetting process. The researchers wore plastic gloves and surgical masks to ensure safety and cleanliness. All tools and equipment were inspected and cleaned before use, and the workspace was organized for efficient experimentation.

Step 2: Processing the Components into Smaller Pieces

Cassava peels were cut into smaller pieces using a knife and grater, while paper waste was shredded into thin strips. Both materials were soaked in water to soften them and then blended into a smooth pulp to achieve a uniform consistency for briquette formation.

Step 3: Molding into Co-Briquettes

The pulped cassava peels and paper waste were mixed with cassava starch and water to form a uniform mixture. The mixture followed the assigned proportions for each treatment. The pulp was pressed into briquette molds, and holes were created at the center of each briquette to improve airflow during combustion.

Step 4: Natural Sun Drying

The molded briquettes were placed on trays and dried under direct sunlight to reduce moisture content. The drying area was kept secure and protected from rain. A multimeter was used to check electrical resistance, with a target value of 28 megohms to confirm adequate drying.

Step 5: Pre-Combustion Quality Observation

After drying, briquettes underwent tests for moisture content, density, and shatter resistance. Mass was measured using a weighing scale, while volume was determined using a caliper ruler. Briquettes were also dropped from a fixed height to assess durability.

Step 6: Combustion Testing and Heat Measurement

Each briquette was burned individually on a charcoal stove. A thermocouple thermometer measured combustion temperature, and a digital stopwatch recorded ignition and burning time. Ash residues were collected after combustion.

Step 7: Comparison with Commercial Briquette Products

The produced briquettes were compared with commercial briquettes based on moisture content, density, shatter resistance, ignition time, burning time, heat output, and ash production.

Step 8: Data Analysis and Conclusion

All observations and measurements were recorded and analyzed. Calculations such as density and combustion efficiency were performed using a calculator. The results were compared across different mixture ratios to determine the most effective briquette formulation.

Data Gathering Procedure

Formulation of the Experimental Setup

The researchers experimented with 7D, M.D. Echavez Street, Villa Fatima, Sudlon, Maguikay, Mandaue City, Cebu. Cassava peels were collected, washed, and sun-dried to reduce moisture content, while paper waste was shredded into small pieces. The materials were prepared according to their designated proportions, then thoroughly mixed with cassava starch, a natural binder, and water to achieve the proper consistency. For each setup, 10 g of cassava starch and 150 mL of water were added, and briquettes with three holes were produced. All briquettes were tested for fuel efficiency, combustion time, density, moisture content, ash content, ignition time, shatter resistance, and emission levels.

Experimental Setups

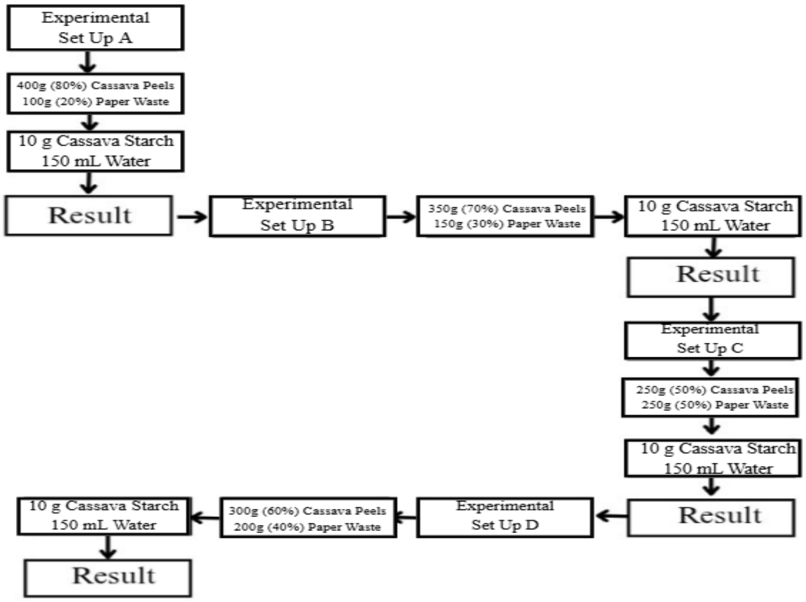

Figure 3:Diagram of the Experimental Set-up for Co-Briquetting Cassava Peels and Paper Waste

Experimental Setup A

Briquettes were produced using 400 g (80%) cassava peels and 100 g (20%) paper waste. Each mixture used 10 g cassava starch and 150 mL water as binders, and the briquettes were molded with three holes. This setup evaluated briquettes with high cassava peel content.

Experimental Setup B

Briquettes were produced using 350 g (70%) cassava peels and 150 g (30%) paper waste, with 10 g cassava starch and 150 mL water as binders. The briquettes had three holes and were used to test briquettes with moderately high cassava peel content.

Experimental Setup C

Briquettes were produced using 250 g (50%) cassava peels and 250 g (50%) paper waste with the same binder and water amounts. This setup evaluated briquettes with equal proportions of cassava peel and paper waste.

Experimental Setup D

Briquettes were produced using 300 g (60%) cassava peels and 200 g (40%) paper waste with 10 g cassava starch and 150 mL water. This setup tested briquettes with higher paper waste content.

Trial 1

Four mixture ratios totaling 500 g were tested: (A) 80:20, (B) 70:30, (C) 50:50, and (D) 60:40 cassava peel to paper waste. Each mixture was combined with 10 g cassava starch and 150 mL water, mixed until uniform, and molded into 3-hole briquettes. The briquettes were sun-dried until their electrical resistance reached 28 megohms. After drying, they were weighed, measured, and tested for moisture content, density, heat output, combustion duration, shatter resistance, and ash production. Results were recorded for analysis.

Trial 2

The same procedures and material ratios were used to evaluate consistency. Adjustments were made based on issues observed in Trial 1, such as drying and ignition problems. Briquettes were dried until reaching 28 megohms resistance and tested again for moisture content, heat output, density, ash content, combustion time, ignition time, and shatter resistance. Environmental conditions were also recorded.

Trial 3

The third trial followed the same procedures with further refinements to improve mixing, drying, and handling. The same ratios, binder, and water amounts were maintained. Measurements for moisture content, heat output, density, combustion duration, ash content, and shatter resistance were recorded. The co-briquettes were also compared with commercial briquettes, and results from all trials were analyzed to determine consistency and overall performance.

Failed Trial Protocol

A trial was considered failed if the briquette did not ignite, collapsed easily, extinguished quickly, produced excessive ash, lost essential measurement data, posed safety hazards, or had extreme moisture content. All failures were documented, causes were identified, and corrected replicates were produced. If the same failure occurred twice, the replicate was replaced. Persistent issues were discussed with the research adviser and necessary adjustments were made. Only valid replicates were included in the analysis, and deviations were noted in the limitations section.

Experimentation Testing

The experimentation was conducted at 7D, M.D. Echavez Street, Villa Fatima Sudlon, Maguikay, Mandaue City, Cebu. Cassava peels and paper waste were used as the primary materials for co-briquettes, with cassava starch as the binder. Four mixture ratios were prepared: 80% cassava peels–20% paper waste, 70%–30%, 60%–40%, and 50%–50%. Each batch used 10 g cassava starch and 150 mL water for mixing. Cassava peels were washed and sun-dried, while paper waste was shredded before molding. Each briquette contained three holes to evaluate airflow during combustion. Equipment such as weighing scales, mixing containers, stirring tools, timers, thermocouple thermometers, and metal containers were used. Three trials were conducted to ensure reliability.

Co-Briquettes

Each setup underwent three consecutive trials under the same environmental conditions, resulting in 12 burns in total. During each trial, the researchers prepared, ignited, and tested the briquettes while recording moisture content, heat output, density, ash content, combustion time, and shatter resistance. Emissions and temperature were also monitored at fixed intervals. Five researchers participated: one monitored time, one recorded data, one documented observations, and two handled preparation and ignition. The briquettes were sun-dried for about one week (9:00 AM–3:00 PM) until electrical resistance reached 28 megohms using a multimeter, confirming adequate dryness before testing.

Statistical Treatment

A one-way analysis of variance (ANOVA) is a statistical method that compares the means of three or more independent groups to determine whether significant differences exist, by analyzing within-group and between-group variability (Chatzi & Doody, 2024). Post-hoc tests, conducted after a significant ANOVA, identify which group means differ, providing detailed pairwise comparisons to clarify the source of the overall significance (Agbangba et al., 2024).

Results and Discussion

The moisture content of the different briquette setups.

Table 3 presents the moisture content of the different briquette setups across three experimental trials, showing variations among Setups A, B, C, D, and the Commercial Briquette (CB) that allow comparison of their drying efficiency and potential fuel performance. Setup D recorded the highest mean moisture content at 289.49%, indicating a very high water-to-biomass ratio, suggesting that the materials retained significant moisture which may weaken structural integrity and reduce combustion efficiency. In contrast, the Commercial Briquette (CB) had the lowest mean moisture content of 14.69%, reflecting a much drier composition likely due to advanced mechanical processing that improves compaction, water removal, and uniformity, resulting in more efficient and reliable combustion. This difference highlights the influence of preparation methods and material handling on moisture retention. These findings are supported by studies such as that of Aal (2023), whose research titled Impact of Biomass Moisture Content on the Physical Properties of Briquettes Produced from Recycled Ficus nitida Pruning Residuals showed that high moisture levels can negatively affect briquette structure and combustion efficiency. Similarly, Saeed et al. (2021), in their study The Production of Rice Husk-Based Briquettes Blended with Kraft Lignin: Effect of Moisture Content on Physical and Chemical Properties, demonstrated that controlled moisture improves combustion efficiency, durability, and energy output. Likewise, Ayaa et al. (2025) emphasized that lower moisture content enhances briquette strength, handling, and combustion performance. Overall, these studies support the present results by confirming that proper moisture control is essential in briquette production, since excessive moisture can lead to weaker structure, cracking, and reduced energy output, while lower moisture contributes to more durable and efficient fuel.

	Setup A	**Setup B**	**Setup C**	**Setup D**	**CB**
Trial 1	138.64 %	239.68 %	243.55 %	313.33 %	21.62 %
Trial 2	237.10 %	268.25 %	351.92 %	193.15 %	10.26 %
Trial 3	141.38 %	247.14 %	156.47 %	362 %	12.20 %
Average	**172.37 %**	**251. 69 %**	**250.65 %**	**289.49 %**	**14.69 %**

Table 3. The moisture content of the different briquette setups.

Significant difference between the moisture content of different setups.

Table 4 presents the analysis of significant differences in moisture content among the various briquette setups using ANOVA and pairwise comparisons. The one way analysis of variance revealed a statistically significant difference among the groups, with an F statistic of 8.8097 and a p value of 0.002583, which is below the 0.05 level of significance. This indicates that the variations in the mean moisture content across the groups are unlikely to have occurred by chance. The larger between groups mean square of 36,194.04 compared with the within groups mean square of 4,108.44 further supports the presence of differences among the group means. Because of this, a post hoc analysis using Tukey's Honestly Significant Difference test was conducted to identify which specific groups differed significantly while controlling for Type I error. The pairwise comparison results show that the Commercial Briquette (x5) had a statistically significant difference in moisture content compared with Setup B (x2), Setup C (x3), and Setup D (x4), as shown by p values below 0.05. However, there was no significant difference between the Commercial Briquette and Setup A (x1), although this comparison produced a lower p value than the other non significant pairs. In addition, all comparisons among Setups A, B, C, and D resulted in p values greater than 0.05, indicating that the experimental setups did not significantly differ in moisture content. Overall, the results show that the Commercial Briquette differs in moisture content from most of the experimental briquette formulations, while the experimental setups themselves have similar moisture characteristics. These findings are supported by the study of Prasetyadi et al. (2024) entitled "Alternative Method for Stopping the Coconut Shell Charcoal Briquette Drying Process," which emphasized the importance of accurately determining moisture levels in briquettes. Their study showed that measurable properties such as electrical resistance and density can reflect moisture differences, with dry briquettes having much higher resistance than wet ones. This supports the present results because the significant difference observed between the commercial briquette and the produced briquettes indicates that moisture variation can affect measurable physical properties. Therefore, the study reinforces the use of scientific measurements to evaluate drying efficiency and moisture differences in briquette production.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	4	144776.1632	36194.0408	8.8097	0.002583
Error (within groups)	10	41084.4285	4108.4428		
Total	14	185860.5916	13275.7565		

Pair	Difference	SE	Q	Lower CI	Upper CI	Critical Mean	p-value
x1-x2	79.3167	37.0065	2.1433	-92.9224	251.5558	172.2391	0.5758
x1-x3	78.2733	37.0065	2.1151	-93.9658	250.5124	172.2391	0.587
x1-x4	117.12	37.0065	3.1648	-55.1191	289.3591	172.2391	0.2416
x1-x5	157.68	37.0065	4.2609	-14.5591	329.9191	172.2391	0.07689
x2-x3	1.0433	37.0065	0.02819	-171.1958	173.2824	172.2391	1
x2-x4	37.8033	37.0065	1.0215	-134.4358	210.0424	172.2391	0.9464
x2-x5	**236.9967**	**37.0065**	**6.4042**	**64.7576**	**409.2358**	**172.2391**	**0.007538**
x3-x4	38.8467	37.0065	1.0497	-133.3924	211.0858	172.2391	0.9413
x3-x5	**235.9533**	**37.0065**	**6.376**	**63.7142**	**408.1924**	**172.2391**	**0.007764**
x4-x5	**274.8**	**37.0065**	**7.4257**	**102.5609**	**447.0391**	**172.2391**	**0.002663**

*significant at p-value < 0.05; x1 – Setup A, x2 – Setup B, x3 – Setup C, x4 – Setup D and x5 – Commercial briquette

Table 4. Significant difference between the moisture content of different setups.

The density of the different briquette setups.

Table 5 presents the density of the different briquette setups across three experimental trials, including the Commercial Briquette (CB) as a comparative standard. The results show variations in density among the setups, with corresponding average values used to evaluate and compare their overall compactness and material consistency. The Commercial Briquette recorded the highest mean density at 351.01 kg/m^3, indicating a highly compact and tightly bound structure resulting from controlled mechanical processing that improves particle alignment and bonding. In contrast, Setup D exhibited the lowest mean density of 208.13 kg/m^3, indicating a more porous composition and lower compactness, which may be influenced by the properties and mixing ratios of the cassava peels and paper used in the formulation that affect packing efficiency and create more void spaces within the briquette. These differences highlight the importance of both mechanical processing and raw material composition in determining briquette compactness and structural quality. According to the Densified Biomass theory of Reed and Bryant (1978), loose biomass materials can be converted into efficient solid fuel through densification, a process that compresses particles to reduce void spaces, improve bonding, and increase bulk density, resulting in a more compact, durable, and energy-dense briquette that is easier to handle and transport. In relation to the present findings, the higher density observed in the Commercial Briquette reflects stronger mechanical compression and a more consolidated structure, while the lower density in Setup D indicates greater porosity and weaker particle packing. These findings are supported by Limhengh et al. (2021), who reported that pelletizing blended biomass wastes improves compactness and structural integrity through effective densification, producing uniform and tightly bound fuel products that meet commercial standards. Similarly, Imaniraguha et al. (2025) found that briquette density and strength are strongly influenced by biomass ratios and densification methods, demonstrating that appropriate material combinations and processing conditions can significantly improve compactness, mechanical strength, and overall briquette quality.

	Setup A	**Setup B**	**Setup C**	**Setup D**	**CB**
Trial 1	289.47 kg/m^3	240.92 kg/m^3	322.17 kg/m^3	200.33 kg/m^3	328.89 kg/m^3
Trial 2	233.08 kg/m^3	232.47 kg/m^3	191.88 kg/m^3	232.85 kg/m^3	364.49 kg/m^3
Trial 3	286.18 kg/m^3	206.19 kg/m^3	288.62 kg/m^3	191.20 kg/m^3	359.65 kg/m^3
Average	**269.56 kg/m^3**	**226.53 kg/m^3**	**267.56 kg/m^3**	**208.13 kg/m^3**	**351.01 kg/m^3**

Table 5. The density of the different briquette setups.

Significant difference in density between the different setups.

Table 6 presents the results of the analysis of variance (ANOVA) and post hoc comparisons used to determine significant differences in density across the different briquette setups. The one-way ANOVA revealed a statistically significant difference among the groups, with an F-value of 6.7354 and a p-value of 0.006754, indicating that the variation in group means is unlikely due to chance. The between-groups mean square (9104.2537) was higher than the within-groups mean square (1351.6929), suggesting noticeable differences among the setups. A Tukey Honestly Significant Difference (HSD) test was conducted to determine which groups differed significantly. The results showed that commercial briquettes had a significantly higher density compared to setups B and D, with p-values of 0.01336 and 0.005367, respectively, while the other pairwise comparisons showed no significant differences (p-values > 0.05), indicating that most experimental setups had comparable densities. These findings suggest that although the commercial briquettes exhibited greater compactness and structural strength, the experimental formulations generally produced similar density levels. This result is supported by the study of Waheed et al. (2023), entitled "Dataset on the Performance Characteristics of Briquettes from Selected Agricultural Wastes Using a Piston-Type Briquetting Machine," which reported that material composition and processing methods influence the physical strength and compactness of briquettes. Their findings also indicated that higher density improves combustion performance and fuel quality, supporting the present result that the commercial briquettes, having higher density, demonstrate better structural quality compared to some experimental setups.

Source	**DF**	**Sum of Square**	**Mean Square**	**F Statistic**	**P-value**
Groups (between groups)	4	36417.0149	9104.2537	6.7354	0.006754
Error (within groups)	10	13516.9289	1351.6929		
Total	14	49933.9438	3566.7103		

Pair	**Difference**	**SE**	**Q**	**Lower CI**	**Upper CI**	**Critical Mean**	**p-value**
x1-x2	43.05	21.2265	2.0281	-55.7444	141.8444	98.7944	0.6218
x1-x3	2.02	21.2265	0.09516	-96.7744	100.8144	98.7944	1
x1-x4	61.45	21.2265	2.895	-37.3444	160.2444	98.7944	0.3121
x1-x5	81.4333	21.2265	3.8364	-17.361	180.2277	98.7944	0.1214
x2-x3	41.03	21.2265	1.933	-57.7644	139.8244	98.7944	0.6599
x2-x4	18.4	21.2265	0.8668	-80.3944	117.1944	98.7944	0.9697
x2-x5	**124.4833**	**21.2265**	**5.8645**	**25.689**	**223.2777**	**98.7944**	**0.01336**
x3-x4	59.43	21.2265	2.7998	-39.3644	158.2244	98.7944	0.3403
x3-x5	83.4533	21.2265	3.9316	-15.341	182.2477	98.7944	0.1097
x4-x5	**142.8833**	**21.2265**	**6.7314**	**44.089**	**241.6777**	**98.7944**	**0.005367**

*significant at p-value < 0.05; x1 – Setup A, x2 – Setup B, x3 – Setup C, x4 – Setup D and x5 – Commercial briquette

Table 6. *Significant difference in density between the different setups.*

The heat output of the different briquette setups.

Table 7 presents the heat output of the different briquette setups (A, B, C, D) and the Commercial Briquette (CB) across three trials, including the computed average temperature for each setup to compare their combustion performance. Setup C recorded the highest mean heat output at 554.83 °C, indicating the greatest thermal intensity and suggesting that the ratio and properties of cassava peels and paper allowed more efficient combustion and greater energy release during burning. In contrast, Setup A showed the lowest mean heat output at 331.17 °C, reflecting lower combustion temperature likely caused by its material composition that limited heat generation. The difference between the highest and lowest values shows that briquette composition significantly affects combustion behavior and thermal efficiency. This observation is supported by Turns (1996) in An Introduction to Combustion: Concepts and Applications, which explains that efficient energy release depends on proper heat and mass transfer and effective interaction between fuel and air, indicating that Setup C likely allowed better heat transfer and gas movement during combustion. Similarly, Ahmad et al. (2024), in the study Optimization of Calorific Value in Briquette Made of Coconut Shell and Cassava Peel by Varying Mass Fraction and Drying Temperature, reported that specific biomass ratios significantly influence heat performance, supporting the result that Setup C achieved the highest heat output. In addition, Patcharee and Naruephat (2015), in A Study on How to Utilize Waste Paper and Coffee Residue for Briquettes Production, emphasized that briquette composition strongly affects fuel performance, reinforcing that balanced biomass mixtures can improve combustion stability and increase thermal efficiency, as observed in Setup C.

	Setup A	**Setup B**	**Setup C**	**Setup D**	**CB**
Trial 1	313.6 °C	485.2 °C	564.8 °C	553.9 °C	400.0 °C
Trial 2	291.3 °C	325.9 °C	550.8 °C	543.5 °C	447.3 °C
Trial 3	388.6 °C	399.9 °C	548.9 °C	481.3 °C	445.5 °C
Average	**331.17 °C**	**403.67 °C**	**554.83 °C**	**526.23 °C**	**430.93 °C**

Table 7. The heat output of the different briquette setups.

Significant difference between the heat output of different setups.

The results presented in Table 8 show the significant differences in heat output among the various briquette setups based on the ANOVA and pairwise comparison analyses. The one-way ANOVA indicates a statistically significant difference among the five groups, with an F-statistic of 11.106 and a p-value of 0.001064, which is below the 0.05 significance level, suggesting that at least one group differs significantly from the others. A Tukey HSD post hoc test was conducted to determine which specific groups contributed to this difference. The pairwise comparisons reveal that Setups C and D form one homogeneous group, while Setups A, B, and the commercial briquette form another group, with the commercial briquette showing intermediate performance. The largest differences are observed between Setup A and Setups C and D, indicating a clear separation in their properties. Setup B shows intermediate behavior but is closer in performance to Setup A and the commercial briquette. Some comparisons, such as x1–x3 and x1–x4, are statistically significant ($p < 0.05$), confirming meaningful differences, while others, such as x1–x2 and x4–x5, are not significant, indicating similar performance. Overall, the findings show distinct groupings among the briquette setups, separating higher-performing samples from lower-performing ones.

Source	**DF**	**Sum of Square**	**Mean Square**	**F Statistic**	**P-value**
Groups (between groups)	4	100293.6593	25073.4148	11.106	0.001064
Error (within groups)	10	22576.3732	2257.6373		
Total	14	122870.0325	8776.4309		

Pair	**Difference**	**SE**	**Q**	**Lower CI**	**Upper CI**	**Critical Mean**	**p-value**
x1-x2	72.5	27.4326	2.6428	-55.1792	200.1792	127.6792	0.3905
x1-x3	**223.6667**	**27.4326**	**8.1533**	**95.9875**	**351.3459**	**127.6792**	**0.001319**
x1-x4	**195.0667**	**27.4326**	**7.1108**	**67.3875**	**322.7459**	**127.6792**	**0.003647**
x1-x5	99.7667	27.4326	3.6368	-27.9125	227.4459	127.6792	0.1498
x2-x3	**151.1667**	**27.4326**	**5.5105**	**23.4875**	**278.8459**	**127.6792**	**0.01958**
x2-x4	122.5667	27.4326	4.4679	-5.1125	250.2459	127.6792	0.06133

x2-x5	27.2667	27.4326	0.994	-100.4125	154.9459	127.6792	0.9512
x3-x4	28.6	27.4326	1.0426	-99.0792	156.2792	127.6792	0.9426
x3-x5	123.9	27.4326	4.5165	-3.7792	251.5792	127.6792	0.05815
x4-x5	95.3	27.4326	3.474	-32.3792	222.9792	127.6792	0.1773

*significant at p-value < 0.05; x1 – Setup A, x2 – Setup B, x3 – Setup C, x4 – Setup D and x5 – Commercial briquette

Table 8. Significant difference between the heat output of different setups.

The ash content of the different briquette setups.

Table 9 presents the ash content of the different briquette setups across three experimental trials, showing the variations in residual ash produced by each setup and providing a basis for comparing combustion cleanliness and fuel quality. Setup A and the commercial briquette recorded the highest mean ash content of 0.023 kg, indicating the largest amount of non-combustible residue among the samples, which may be influenced by the composition and ratio of cassava peels and paper that can leave more inorganic material after combustion. In contrast, Setup D exhibited the lowest mean ash content at 0.009 kg, reflecting a smaller amount of residue likely due to a formulation with a higher proportion of combustible material that burns more completely. These results highlight that the properties and ratios of raw materials directly affect ash content, where higher inorganic content produces more ash while higher combustibility results in lower ash formation. The findings are supported by Dinesha and Kumar (2019) in their study Biomass Briquettes as an Alternative Fuel: A Comprehensive Review, which emphasized that high ash content can reduce fuel quality and combustion efficiency, consistent with the higher ash content observed in Setup A and the commercial briquette. Similarly, Sweya et al. (2024) in Briquette Quality Assessment from Corn Husk, Bagasse, and Cassava Roots Using Banana Peels, Wastepaper, and Clay Soil reported that briquettes containing wastepaper show better burning characteristics and improved fuel efficiency, which supports the lower ash content recorded in Setup D. Furthermore, Idah and Mopah (2013) in Comparative Assessment of Energy Values of Briquettes from Some Agricultural By-Products with Different Binders found that cassava peel materials contribute to better combustion behavior and energy performance, supporting the present result that the lower ash content in Setup D indicates improved fuel performance and cleaner combustion when cassava peels and paper waste are combined.

	Setup A	**Setup B**	**Setup C**	**Setup D**	**CB**
Trial 1	0.026 kg	0.014 kg	0.014 kg	0.008 kg	0.024 kg
Trial 2	0.020 kg	0.010 kg	0.009 kg	0.009 kg	0.022 kg
Trial 3	0.024 kg	0.012 kg	0.014 kg	0.010 kg	0.022 kg
Average	**0.023 kg**	**0.012 kg**	**0.012 kg**	**0.009 kg**	**0.023 kg**

Table 9. The ash content of the different briquette setups.

Significant difference in *ash content* across *different setups.*

Table 10 presents the significant differences in ash content among the various briquette setups, highlighting both between-group and within-group variations and identifying which pairs of setups exhibit statistically meaningful differences. The ANOVA results reveal a statistically significant difference among the groups, with an F-statistic of 27.5903 and a p-value of 0.00002211, indicating that the variation between groups is considerably greater than the variation within groups; this is further supported by the between-group sum of squares (0.0005297) being much higher than the within-group sum of squares (0.000048). A post hoc analysis using Tukey's Honestly Significant Difference (HSD) test was conducted to determine which specific groups differ, and the pairwise comparison shows that setups B, C, and D have significantly lower ash content than the commercial briquette (x1–x2: difference = 0.01133, p = 0.0006283; x1–x3: difference = 0.011, p = 0.0007971; x1–x4: difference = 0.01433, p = 0.00008823), while Setup A does not significantly differ from the commercial briquette (x1–x5: difference = 0.0006666, p = 0.9952), indicating comparable ash levels. Comparisons among the experimental setups further show that differences between B, C, and D are generally not statistically significant, but each of these setups differs substantially from the commercial briquette, suggesting that the experimental formulations—particularly setups B, C, and D—are more effective in reducing ash content and improving combustion quality. These findings are supported by the study of Sweya et al. (2024), entitled "Briquette Quality Assessment from Corn Husk, Bagasse, and Cassava Roots Using Banana Peels, Wastepaper, and Clay Soil as Binders," which reported that the type of raw materials used in briquette production greatly influences ash content and overall fuel quality; similarly, the present results show that certain material combinations produce lower ash levels and cleaner-burning briquettes, reinforcing the conclusion that selecting appropriate biomass materials can significantly improve briquette performance and efficiency.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	4	0.0005297	0.0001324	27.5903	0.00002211
Error (within groups)	10	0.000048	0.0000048		
Total	14	0.0005777	0.00004127		

Pair	Difference	SE	Q	Lower CI	Upper CI	Critical Mean	p-value
x1-x2	**0.01133**	**0.001265**	**8.9598**	**0.005446**	**0.01722**	**0.005887**	**0.0006283**
x1-x3	**0.011**	**0.001265**	**8.6963**	**0.005113**	**0.01689**	**0.005887**	**0.0007971**
x1-x4	**0.01433**	**0.001265**	**11.3315**	**0.008446**	**0.02022**	**0.005887**	**0.00008823**
x1-x5	0.0006666	0.001265	0.527	-0.005221	0.006554	0.005887	0.9952
x2-x3	0.0003333	0.001265	0.2635	-0.005554	0.006221	0.005887	0.9997
x2-x4	0.003	0.001265	2.3717	-0.002887	0.008887	0.005887	0.4872
x2-x5	**0.01067**	**0.001265**	**8.4328**	**0.004779**	**0.01655**	**0.005887**	**0.001015**
x3-x4	0.003333	0.001265	2.6352	-0.002554	0.009221	0.005887	0.3931
x3-x5	**0.01033**	**0.001265**	**8.1693**	**0.004446**	**0.01622**	**0.005887**	**0.001299**
x4-x5	**0.01367**	**0.001265**	**10.8045**	**0.007779**	**0.01955**	**0.005887**	**0.0001329**

*significant at p-value < 0.05; x1 – Setup A, x2 – Setup B, x3 – Setup C, x4 – Setup D and x5 – Commercial briquette

Table 10. Significant difference in *ash content* across *different setups.*

The combustion time of different briquette setups.

Table 11 presents the combustion time of the different briquette setups measured across three trials, providing a comparative overview of how long each briquette type sustains burning under controlled conditions. Setup A recorded the highest mean combustion time of 9:06 minutes, indicating a significantly slower burn rate compared to the other setups, which suggests a denser or more compact composition resulting from the specific mixing ratios of cassava peels and paper that lead to slower ignition and more sustained burning. In contrast, Setup D exhibited the lowest mean combustion time at 2:25 minutes, reflecting a faster burn rate and shorter combustion duration likely influenced by a material composition that allows faster heat transfer and quicker fuel consumption. These results show that combustion duration is strongly affected by the density, composition, and structural properties of the briquettes. This observation is supported by Reed and Bryant (1978) in the study *"Densified Biomass: A New Form of Solid Fuel,"* which explains that loose biomass materials can be compacted into denser solid fuels such as briquettes to improve handling and combustion efficiency; higher density increases compactness and causes slower burning with more sustained heat release, consistent with the longer combustion time observed in Setup A. Similarly, Terhider and Ediba (2021) in *"Investigation of the Combustion Characteristics of Briquettes Produced from Cassava Peels, Mango Nuts, and Orange Peels"* reported that variations in biomass composition and compaction pressure significantly influence burning behavior, supporting the present findings where different setups produced varying combustion times, with Setup D burning the fastest and Setup A the slowest. In addition, Anggraeni et al. (2021) in *"Effects of Particle Size and Composition of Cassava Peels and Rice Husk on the Briquette Performance"* found that biomass ratios and particle size affect briquette density, combustion behavior, and fuel efficiency, further confirming that differences in material composition can alter burning characteristics and explain the variations in combustion duration observed among the briquette setups.

	Setup A	Setup B	Setup C	Setup D	CB
Trial 1	07:59 min	02:06 min	02:26 min	01:37 min	03:04 min
Trial 2	10:04 min	03:11 min	02:27 min	01:44 min	02:57 min
Trial 3	08:59 min	03:24 min	03:12 min	03:52 min	02:59 min
Average	**9:06 min**	**2:53 min**	**02:41 min**	**2:25 min**	**3:00 min**

Table 11. The combustion time of different briquette setups.

Significant difference in combustion time across the different setups.

Table 12 presents the analysis of combustion time differences among briquette setups, including overall ANOVA results and pairwise comparisons. The one-way ANOVA shows a statistically significant difference among groups, with an F-statistic of 35.1212 and a p-value of 0.000007344, well below 0.05. The between-group variance (23.6845) is much higher than the within-group variance (0.6744), indicating that the observed differences are mainly due to the treatment effect.

Post hoc analysis using the Tukey HSD test reveals that Setup A has a significantly longer combustion time than all other setups, with mean differences ranging from 6.011 to 6.605 minutes and p-values below 0.05, suggesting its formulation contributes to superior burn performance. In contrast, Setups B, C, D, and the commercial briquette show minimal differences (0.1057–0.5943 minutes) and high p-values (0.8956–0.9998), indicating no significant variation among them. These results demonstrate that while Setup A is distinct in combustion efficiency, the other setups perform similarly, likely due to comparable material properties or structural integrity. The findings align with Terhider and Ediba (2021), who showed that variations in biomass composition and compaction pressure significantly affect briquette burning behavior, supporting the conclusion that optimizing composition and structure is essential for improved combustion performance.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	4	94.7378	23.6845	35.1212	0.000007344
Error (within groups)	10	6.7436	0.6744		
Total	14	101.4815	7.2487		

Pair	Difference	SE	Q	Lower CI	Upper CI	Critical Mean	p-value
x1-x2	**6.1167**	**0.4741**	**12.9011**	**3.91**	**8.3234**	**2.2067**	**0.00002814**
x1-x3	**6.3167**	**0.4741**	**13.323**	**4.11**	**8.5234**	**2.2067**	**0.00002109**
x1-x4	**6.6053**	**0.4741**	**13.9318**	**4.3986**	**8.812**	**2.2067**	**0.00001408**
x1-x5	**6.011**	**0.4741**	**12.6783**	**3.8043**	**8.2177**	**2.2067**	**0.00003288**
x2-x3	0.2	0.4741	0.4218	-2.0067	2.4067	2.2067	0.998
x2-x4	0.4887	0.4741	1.0307	-1.718	2.6954	2.2067	0.9448
x2-x5	0.1057	0.4741	0.2229	-2.101	2.3124	2.2067	0.9998
x3-x4	0.2887	0.4741	0.6088	-1.918	2.4954	2.2067	0.9917
x3-x5	0.3057	0.4741	0.6447	-1.901	2.5124	2.2067	0.9897
x4-x5	0.5943	0.4741	1.2536	-1.6124	2.801	2.2067	0.8956

*significant at p-value < 0.05; x1 – Setup A, x2 – Setup B, x3 – Setup C, x4 – Setup D and x5 – Commercial briquette

Table 12. Significant difference in combustion time across the different setups.

The ignition time of different briquette setups.

Table 13 shows the ignition times of different briquette setups across three trials, providing insight into their ease of ignition and combustion performance. Setup A had the highest mean ignition time of 23:35 minutes, indicating slower combustion, likely due to a denser structure or less reactive cassava peel–paper composition, while Setup D had the lowest mean ignition time of 12:22 minutes, reflecting faster ignition from a more porous structure or higher proportion of combustible components. These differences highlight how material composition, structural characteristics, and moisture content directly affect ignition, as supported by Aal (2023), who found that optimal moisture improves ignition efficiency, whereas higher moisture delays burning and may cause structural defects. Similarly, Saeed et al. (2021) showed that proper moisture enhances porosity and airflow, leading to faster ignition and higher calorific value, aligning with Setup D's performance. Additionally, Terhider and Ediba (2021) demonstrated that lower compaction pressure and suitable material mixtures reduce ignition time, explaining why Setup D ignited quickly, while the denser composition or higher compaction in Setup A resulted in slower combustion.

	Setup A	Setup B	Setup C	Setup D	CB
Trial 1	38:56 min	24:38 min	28:36 min	22.13 min	26:05 min
Trial 2	19:47 min	10:39 min	14:32 min	09:43 min	21:05 min
Trial 3	12:02 min	08:35 min	10:42 min	05:11 min	19:47 min
Average	**23:35 min**	**14:37 min**	**17:56 min**	**12:22 min**	**22:19 min**

Table 13. The ignition time of different briquette setups.

Significant difference between the ignition times of the different setups.

Table 14 presents the ANOVA results for ignition time across different briquette setups, showing no statistically significant differences among the groups. The calculated F-statistic of 0.7804 and p-value of 0.5629 exceed the conventional 0.05 significance threshold, indicating that the observed variation between group means is likely due to random chance rather than a systematic effect. The between-group sum of squares (278.2344) is small relative to the within-group sum of squares (891.3737), further suggesting minimal differences among groups, and therefore no post hoc analysis was required. These findings imply that the treatments or conditions applied did not produce a measurable impact on ignition time. Supporting this, Prasetyadi et al. (2024), in their study "Alternative Method for Stopping the Coconut Shell Charcoal Briquette Drying Process," found that using electrical resistance and density to assess briquette dryness showed that variations in physical properties, particularly moisture, may not always affect performance indicators such as ignition time. This reinforces the idea that once briquettes reach a sufficient dryness threshold, ignition time remains relatively consistent across different production setups.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	4	278.2344	69.5586	0.7804	0.5629
Error (within groups)	10	891.3737	89.1374		
Total	14	1169.608	83.5434		

Table 14. Significant difference between the ignition times of the different setups.

The shatter resistance of the different briquette setups.

Table 15 presents the shatter resistance of the various briquette setups, measured across three trials to assess structural durability. Setups A, B, and the Commercial Briquette (CB) demonstrated superior resistance with consistent mean scores of 4, showing no visible cracking and minimal fragment loss, indicating they effectively emulate professional-grade fuel. Setup C showed moderate resistance with a score of 3, producing small cracks and noticeable fragmentation, while Setup D performed the poorest with a mean score of 2, frequently breaking in half due to weak internal bonding. The consistency across trials indicates reliable results, confirming that Setups A and B possess the necessary resilience for handling and transport. These findings align with the theory of densification described by Thomas Reed and Becky Bryant (1978), which states that compressing loose biomass into solid forms improves strength, handling, and energy efficiency, as well as with studies by Mng'onya et al. (2025) and Lomunyak et al. (2024), which emphasize that appropriate material composition, binder type, and proportion directly influence mechanical strength, impact resistance, and durability. Overall, the high shatter resistance of Setups A and B reflects effective densification and binder formulation, while the poor performance of Setup D highlights inadequate bonding and reduced structural stability.

	Setup A	Setup B	Setup C	Setup D	CB
Trial 1	4	4	3	2	4
Trial 2	4	4	3	2	4
Trial 3	4	4	3	2	4
Average	4	4	3	2	4

*Legend: 5- no crack no fragments loss, 4- no cracks, minor fragments loss, 3- small cracks, noticeable fragment loss, 2- breaks in half, 1- shatter in multiple fragments and complete break

Table 15. The shatter resistance of the different briquette setups.

Overall performance of each setup using the *Weighted Performance Index*

Table 16 summarizes the overall performance of the briquette setups using the Weighted Performance Index across seven key fuel properties: moisture content, density, heat output, ash content, combustion time, ignition time, and shatter resistance, with lower scores indicating better performance. The commercial briquette achieved the lowest index, reflecting the highest overall performance, while among the experimental briquettes, Setup C, composed of 250 g cassava peels and 250 g paper waste, showed the most favorable performance due to its high heat output, low ash content, and satisfactory density. Although individual fuel properties varied little among the experimental setups, the Weighted Performance Index revealed discernible differences, highlighting Setup C as the most viable formulation. This outcome aligns with the theory presented in Densified Biomass: A New Form of Solid Fuel by Thomas Reed and Becky Bryant (1978), which emphasizes that densification enhances fuel density, handling, and combustion efficiency. Similarly, Turns (1996) explains that efficient combustion relies on effective heat and mass transfer, reflected in Setup C's high heat output and moderate combustion and ignition times, which contribute to its low weighted index. The findings are also consistent with Imaniraguha et al. (2025), who demonstrated that balanced biomass ratios improve mechanical strength and energy performance, supporting the superior performance of Setup C among the experimental briquettes.

Briquette Setup	Moisture Content	Density	Heat Output	Ash Content	Combustion Time	Ignition Time	Shatter Resistance	Weighted Performance Index	Overall Performance Rank
Setup A	Moderate	Moderate	Low	High	Very High	Low	High	3.3	4
Setup B	Moderate	Moderate	Moderate	Low	Moderate	Moderate	High	3.15	3
Setup C	Moderate	High	Very High	Low	Moderate	Moderate	Moderate	2.65	**2 (Best Experimental)**
Setup D	High	Low	High	Very Low	Low	Very High	Low	3.25	5
Commercial Briquette (CB)	Very Low	Very High	Moderate	High	Moderate	Low	High	2.45	**1 (Best Overall)**

*lower score = better overall performance

Table 16. Overall performance of each setup using the Weighted Performance Index

The results of this study demonstrate that co-briquetting cassava peels and paper waste produces biomass fuels with varying physical and combustion characteristics, strongly influenced by material composition and processing conditions. Among the experimental setups, Setup C (250 g cassava peels: 250 g paper waste) exhibited the most balanced and favorable performance, achieving the highest heat output, low ash content, satisfactory density, and moderate combustion and ignition times, making it the most viable alternative to commercial briquettes. While the commercial briquette still showed superior overall performance due to its very low moisture content and high density, the experimental briquettes, particularly Setup C, demonstrated the ability to deliver competitive energy output using readily available waste materials. These findings align with the theory of "Densified Biomass: A New Form of Solid Fuel" by Reed and Bryant (1978), which emphasizes that compacting loose biomass into standardized forms enhances energy density, handling, and usability, thereby supporting the viability of cassava peel and paper waste briquettes. Furthermore, the observations are consistent with Turns' (1996) "Introduction of Combustion" theory, which underscores that efficient energy release depends on effective heat and mass transfer within the fuel, explaining why properly proportioned and densified briquettes like Setup C exhibit improved combustion characteristics. Overall, this study confirms that the careful selection of material proportions and densification methods is crucial to producing high-quality biomass fuels, highlighting the strong potential of cassava peels and paper waste as sustainable, efficient, and environmentally responsible alternatives for future energy applications.

Conclusion and Implications

Conclusion

Briquettes produced through the co-briquetting of cassava peels and paper waste demonstrate strong potential as an alternative biomass fuel, with variations in the cassava peel–paper waste ratio significantly influencing key fuel properties such as moisture content, density, heat output, ash content, combustion time, ignition time, and shatter resistance. Among the tested formulations, Setup C achieved the most balanced and efficient overall performance, while commercial briquettes remained superior in terms of density and overall consistency, highlighting the importance of optimizing material ratios to enhance fuel quality, durability, and combustion efficiency in sustainable briquette production.

Implication

The outcomes are consistent with Reed and Bryant’s densification theory (1978), which explains that compacting loose biomass enhances durability and increases energy density, as well as with Turns’ combustion theory (1996), which emphasizes the importance of fuel composition and structure in achieving efficient heat release and reduced emissions. However, the relatively high moisture content and performance variability observed in some setups highlight the need for improvements in drying techniques, binder formulation, and compaction pressure. Incorporating improved mechanical and technological methods into the briquetting process is recommended to further strengthen density, structural integrity, and overall performance. In line with Sustainable Development Goals 7, 9, and 11, continued refinement and technological optimization can enable cassava peel–paper waste briquettes to become a viable, sustainable, and environmentally responsible alternative energy source.

Recommendation

Based on the findings and conclusions, the following recommendations are proposed: (1) Students may engage in hands-on projects that demonstrate how science and engineering can address energy and waste challenges. Activities such as co-briquetting can help them recognize local materials as valuable resources for sustainability rather than waste. (2) Local and Rural Communities may adopt co-briquetting practices as an affordable and practical alternative to conventional cooking fuels, transforming household and agricultural waste into useful energy while reducing environmental impact. (3) Environmental Scientists may further explore small-scale fuel innovations using localized data to develop low-emission biofuels and strengthen sustainable waste-to-energy strategies. (4) Inventors may design or improve simple mechanical devices capable of compressing household and agricultural waste into durable briquettes, particularly for areas without access to industrial equipment. (5) Innovators may investigate additional combinations of organic and paper waste to create scalable and adaptable fuel solutions suitable for rural communities. (6) Agriculturists may consider cassava peels and other crop residues as potential supplementary income sources, promoting resource efficiency and farm-level sustainability. (7) Policy Makers may integrate co-briquetting initiatives into local waste management and clean energy programs to convert agricultural and domestic waste into renewable energy solutions. (8) Educators may utilize this work as a practical example in STEM and environmental education to connect theoretical concepts with real-world energy and sustainability applications. (9) Researchers and Future Researchers may build upon the methodology and experimental data presented to further examine co-briquetting processes, test alternative waste combinations, enhance briquette performance, and develop efficient, locally appropriate briquette molds.

Acknowledgements

The researchers sincerely express their deepest gratitude to Dr. Adrian M. Abarquez, Inquiries, Investigations, and Immersion (3Is) instructor at Maguikay High School, for his consistent guidance, insightful advice, and dedicated mentorship throughout the research process; to Mr. Aljohn S. Agus for his valuable assistance and support in facilitating the printing of this study; to Mr. Rhino Rienz L. Casas, MAEd, for his expertise in the statistical analysis of the data; to Ms. Nathalie Faith P. Matugas, Science Teacher at Maguikay National High School, for her full support for the research project; and to Dr. Bella Verda Oliveros, School Principal, for her approval and support of this research endeavor. Above all, the researchers thank Almighty God for His boundless love, wisdom, and guidance throughout the completion of this study. Any remaining errors or omissions are the sole responsibility of the authors.

Funding

This research received no external funding from any public, commercial, or not-for-profit funding agency, and no organization provided financial support for the conduct of the study, authorship, or publication of this article.

Competing Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study; all data used were obtained from previously published sources as cited in the reference list.

References

Abdel Aal, A. M., Ibrahim, O. H., Al-Farga, A., & El Saeidy, E. A. (2023). Impact of biomass moisture content on the physical properties of briquettes produced from recycled ficus nitida pruning residuals. *Sustainability, 15*(15), 11762.

Abushammala, H., Masood, M. A., Ghulam, S. T., & Mao, J. (2023). On the conversion of paper waste and rejects into high-value materials and energy. *Sustainability, 15*(8), 6915. https://doi.org/10.3390/su15086915

Ahmad, S., Winarso, K., Yusron, R., & Amar, S. (2024). Optimization of calorific value in briquette made of coconut shell and cassava peel by varying mass fraction and drying temperature. In *E3S Web of Conferences* (Vol. 499, p. 01009). EDP Sciences.

Allam, I. (2025). Implementation of factorial ANOVA in completely randomized block designs using C programming.

Anggraeni, S., Hofifah, S. N., Nandiyanto, A. B. D., & Bilad, M. R. (2021). Effects of particle size and composition of cassava peels and rice husk on the briquette performance. *Journal of Engineering Science and Technology, 16*(1), 527–542.

Arachchige, U. S. P. R. (2021). Briquettes production as an alternative fuel. *Nature Environment and Pollution Technology, 20*(4), 1661–1668. https://doi.org/10.46488/NEPT.2021.v20i04.029

Ayaa, F., Oyedotun, K., Lubwama, M., Iwarere, S. A., Daramola, M. O., & Kirabira, J. B. (2025). Production and characterization of densified briquettes from nanocomposite biochar-cellulose nanocrystal (Biochar-CNC) reinforced with polyvinyl alcohol (PVA). *Waste and Biomass Valorization, 16*(5), 2075–2095.

Desiderio, L. (2024, February 13). JICA leads project to reprocess food waste. *Philstar.com*. https://www.philstar.com/business/2024/02/14/2333107/jica-leads-project-reprocess-food-waste

Dinesha, P., Kumar, S., & Rosen, M. A. (2019). Biomass briquettes as an alternative fuel: A comprehensive review. *Energy Technology, 7*(5), 1801011.

Genuino, A. F. R., Tancuan, J. M. M., Ventura, Q. F., Santos, A. L. S., Foo, K. K. R., Samaco, X. M. F., Armada, L. T. A., Lemoncito, G. L. F., Padrique, M. I. B., Almira, G. D. P., Torres, A. R. C., Calamlam, J. M. M., & Gamboa, G. B. (n.d.). Evaluation of bio briquettes made from *Musa acuminata* Colla, *Musa acuminata* and *Musa balbisiana* silk, and *Citrus reticulata* and *Citrus sinensis* peels. *Animo Repository*. https://animorepository.dlsu.edu.ph/sinaya/vol1/iss2/7/

Homdoung, N., Dussadee, N., Sasujit, K., Kiatsiriroat, T., & Tippayawong, N. (2019). Performance investigation of a gasifier and gas engine system operated on municipal solid waste briquettes. *International Journal of Renewable Energy Development, 8*(2), 179–186.

Ibitoye, S. E., Ajimotokan, H. A., Adeleke, A. A., & Loha, C. (2023). Effect of densification process parameters on the physico-mechanical properties of composite briquettes of corncob and rice husk. *Materials Today: Proceedings*.

Idah, P. A., & Mopah, E. J. (2013). Comparative assessment of energy values of briquettes from some agricultural by-products with different binders.

Imaniraguha, J., Mushimiyimana, T., Lucas, C., & Condo, A. (2025). Production and characterization of briquettes from *Panicum maximum* Jacq. (Guinea grass) and cassava peel waste. *Energy Reports, 14*, 1043–1050.

Limhengha, S., Mahathaninwong, N., Chucheep, T., Karrila, S., & Tipayanon, T. (2021). Making blends of agarwood waste with empty palm bunches or rubber wood sawdust for pelletized biofuels. *BioResources, 16*(2), 2971–2986. https://doi.org/10.15376/biores.16.2.2971-2986

Lomunyak, G., Osodo, B., Njoka, F., & Kombe, E. (2024). Characterization, optimization and emission analysis of manually made charcoal dust briquettes with starch, paper and algae binders. *Heliyon, 10*(24).

Mascardo, I. H. (2025, July 16). Cebu City government: P407 million garbage expenses flagged. *Philstar.com*. https://www.philstar.com/the-freeman/cebu-news/2025/07/17/2458614/cebu-city-government-p407-million-garbage-expenses-flagged

Mbamalu, E. E., & Mohammed, I. Y. (2024). Co-valorisation of cassava peel and rice husk to biofuel precursor via intermediate pyrolysis: Kinetics, thermodynamic and pyrolytic oil characterisation. *Waste Management Bulletin, 2*(4), 194–208. https://doi.org/10.1016/j.wmb.2024.11.004

Mng'onya, A. C., Moirana, R., Maagi, M. T., & Chacha, N. (2025). A comparative study of the adhesive effects of cassava peels, banana peels, and potato peels on the durability of briquettes made from coconut husk charcoal. *AIP Advances, 15*(5).

Patcharee, P., & Naruephat, T. (2015). A study on how to utilize waste paper and coffee residue for briquettes production. *International Journal of Environmental Science and Development, 6*(3), 201–204.

Philippine Statistics Authority – Central Visayas. (2024, October 28). *2024 first semester other crops situation report in the province of Cebu*. https://rsso07.psa.gov.ph/content/2024-first-semester-other-crops-situation-report-province-cebu

Prasetyadi, A., Sambada, R., & Purwadi, P. K. (2024). Alternative method for stopping the coconut shell charcoal briquette drying process. In *E3S Web of Conferences* (Vol. 475, p. 01007). EDP Sciences.

Appendices

No appendices are attached in this study.