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Sustainable Alternatives To Wood Charcoal: Food Waste Briquettes For Energy And Environmental Conservation

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ABSTRACT

The continued reliance on wood charcoal for cooking in the Philippines has led to deforestation, air pollution, and health hazards, particularly in rural and low-income communities. This study investigates the potential of non-carbonized food waste—specifically banana and calamansi peels—as a sustainable, thermodynamically viable alternative fuel through briquette production. Using an experimental comparative analysis, the research evaluates briquettes with and without natural binders against commercial wood charcoal across key fuel parameters: moisture content, volatile combustible matter, ash content, fixed carbon, and gross calorific value. Results indicate that banana peel briquettes with binder achieved the highest calorific value (4026 cal/g), making them suitable for household cooking, while calamansi peel briquettes with binder showed the lowest ash content (5.0%), suggesting cleaner combustion. Although traditional wood charcoal maintains higher fixed carbon and energy output, food waste briquettes offer significant environmental benefits—lower emissions, reduced ash, and the repurposing of organic waste—aligning with circular economy and sustainable development goals. The findings support the feasibility of food waste briquettes as clean, affordable, and eco-friendly alternatives for communities, while highlighting the need for further studies on long-term combustion behavior and emissions. The study ultimately advocates for localized briquette production using available food waste to promote waste-to-energy solutions, reduce environmental degradation, and improve energy access.

Keywords: *Briquettes, Charcoal, sustainable alternatives, Energy, Energy Conservation.*

INTRODUCTION

In the Philippines, heavy reliance on wood charcoal for cooking contributes significantly to deforestation, air pollution, and health risks, particularly in rural and low-income communities. As the country moves toward sustainable development, exploring renewable energy alternatives has become increasingly important. One promising solution is the conversion of food waste—such as banana and calamansi peels—into briquettes, which offers the dual benefits of reducing organic waste and providing a clean, affordable fuel source. Recent studies highlight the viability of using food and agricultural waste for briquette production. Food waste can be converted into charcoal briquettes through methods like microwave pyrolysis, and natural binders such as starch or carboxymethyl cellulose enhance their physical quality (Idris et al., 2021). Mixing decomposed food waste with tree-based materials has also been shown to improve combustion performance (Josiane et al., 2022). Other agricultural residues like coconut shells and corn cobs are effective biomass inputs as well (Aporto et al., 2023).

Beyond the Philippine context, food waste briquettes are gaining global attention. Thermochemical upcycling and engineered biochar from food waste are emerging as sustainable energy solutions with potential applications in pollution mitigation and climate action (Yuan et al., 2023). However, the environmental impact of traditional wood charcoal remains severe—about 3 billion people still use polluting fuels, leading to millions of premature deaths each year due to indoor air pollution (Adair-Rohani, 2021). Charcoal production is also responsible for 1–2.4 Gt CO_2e in emissions annually, accounting for 2–7% of global anthropogenic emissions (Abebaw, 2024). While some studies note that charcoal may reduce particulate matter compared to open wood fires, its overall climate impact per meal is worse than alternatives like LPG or kerosene (Kituyi et al., 2004). Addressing these challenges requires promoting cleaner fuel alternatives such as food waste briquettes.

Additional research supports this transition. Briquettes made from municipal solid waste, including food and garden refuse, have shown adequate compressive strength and energy value (Sowndharya & Praveena, 2023). In regions like sub-Saharan Africa, using food waste as biofuel has contributed to improved waste management and energy access (Bakari et al., 2024). As a whole, the integration of food waste into briquette production offers a practical and sustainable approach to addressing fuel shortages, reducing emissions, and enhancing environmental conservation efforts in the Philippines and beyond.

THE PROBLEM

This study explores the environmental and fuel limitations of traditional wood charcoal and proposes non-carbonized food waste briquettes—specifically from calamansi and banana peels—as a sustainable alternative. It aims to answer: (1) What are the limitations of using traditional charcoal? and (2) Can food waste be converted into efficient, eco-friendly briquettes?

The objective is to assess the feasibility of using calamansi and banana peels to produce briquettes, both with and without natural binders, and compare their fuel properties (moisture content, volatile matter, ash content, fixed carbon, and calorific value) to commercial wood charcoal.

Significantly, this study offers a low-cost, renewable solution by repurposing household waste to reduce landfill accumulation and support environmental goals like deforestation reduction and climate change mitigation. Insights may benefit households, schools, and communities aiming for sustainable energy practices.

The scope is limited to lab-scale analysis of two food waste types in two forms (with and without binder), focusing on thermodynamic performance. It does not include mass production or field testing.

RELATED LITERATURE

Charcoal production significantly contributes to forest degradation and carbon emissions in sub-Saharan Africa. In Tanzania, it causes an annual forest loss of 150,433 hectares, while in Mozambique, 68% of mopane woodlands were degraded over a decade, emitting 1.13 million tons of carbon (Herold et al., 2016; Msuya et al., 2011; Sedano et al., 2020). Globally, forest degradation—mainly from timber harvesting (53%), woodfuel extraction (30%), and fires (17%)—accounts for 25% of emissions related to deforestation (Pearson et al., 2017). These activities also lead to air pollution, soil erosion, and rainfall disruption.

Waste-to-Energy (WtE) technologies offer sustainable alternatives by converting waste into energy through incineration, pyrolysis, gasification, anaerobic digestion, and landfill gas recovery (Qazi & Abushammala, 2020; Alao et al., 2022). The optimal method depends on factors like waste type, cost, and environmental impact, with tools like TOPSIS aiding decision-making (Farooq et al., 2021; Alao et al., 2020). In developing countries, anaerobic digestion is favored due to high organic waste content, while incineration dominates in developed regions (Alao et al., 2022).

Briquetting agricultural waste emerges as a low-cost, eco-friendly WtE solution. Using materials like rice husks, corn cobs, coconut shells, and wastepaper, briquettes provide low-ash, low-moisture fuel (P. Donald et al., 2022; Azunta Aporto et al., 2023; S. Ahmed, 2014). Technologies such as the screw press enhance combustion quality and storage (S. Ahmed, 2014). The process—preparation, pyrolysis, binder use, and densification—produces briquettes suitable for cooking and heating, while also addressing waste management and environmental concerns (Febi Navila Ella Firdani & S. Sudarti, 2022).

FRAMEWORKS

This study is grounded in thermodynamics and the circular economy (CE), supporting sustainable alternatives to wood charcoal. Research shows food waste like banana peels can be converted into briquettes via microwave pyrolysis, with binders such as starch improving quality (Idris et al., 2021). Mixing food waste with coconut husks or sawdust enhances combustion (Josiane et al., 2022), and agricultural by-products like coconut shells and corn cobs serve as effective biomass sources (Aporto et al., 2023).

Thermochemical upcycling into biochar aligns with SDGs focused on clean energy and environmental protection (Yuan et al., 2023), though further studies are needed to optimize processes and assess long-term impacts.

The CE model complements this approach by promoting resource reuse and low-carbon production. It supports SDGs 7, 12, and 13, with broader links to SDGs 6, 8, and 15 (Abdulaziz Aborujilah et al., 2023; Rahmat et al., 2024; Schroeder et al., 2019). CE's benefits are strongest in regenerative systems and waste management, though issues like labor fairness and tech access remain concerns (Schroeder et al., 2019; Aborujilah et al., 2023).

The study's framework includes inputs (calamansi and banana peels), processes (drying, forming, testing), and outputs (calorific value, combustion, sustainability). Banana peel briquettes emit less CO_2 than charcoal (Torres & Aberilla, 2024), and fuel properties improve through hydrothermal carbonization and binder tuning (Sharma et al., 2021). Binder ratio and sawdust content also influence combustion efficiency (Abdul Razak et al., 2023), reinforcing the potential of food waste briquettes as clean, sustainable fuel.

METHODOLOGY

Research Design

This study uses an experimental comparative approach to evaluate non-carbonized calamansi and banana peel briquettes—both with and without binders—as sustainable alternatives to wood charcoal. Laboratory tests assess fuel properties, including moisture content, volatile matter, ash content, fixed carbon, and calorific value, to determine energy efficiency and environmental performance.

Studies support the viability of biomass briquettes, showing comparable or superior qualities to traditional charcoal (Kumar et al., 2020; Idris et al., 2021; Shiferaw et al., 2017; Mibulo et al., 2023). While binders like starch or carboxymethyl cellulose enhance structure, they may slightly lower calorific value (Idris et al., 2021). Carbonized briquettes generally offer higher energy density, but uncarbonized ones provide environmental advantages, including lower emissions, longer burn time, and reduced ash (Shiferaw et al., 2017; Mibulo et al., 2023).

Sample Preparation

This study uses calamansi and banana peels to produce non-carbonized briquettes in two forms: with and without a natural binder (e.g., cassava starch). Standardized drying and size reduction methods are applied to ensure consistent formation and testing.

Literature supports the use of banana peels and other food wastes for briquettes, citing high heating value and bulk density. Banana peel–rice straw briquettes reach 610–660 kg/m^3 and 20.98–21.26 MJ/kg (Duangkham & Thuadaij, 2023). High-pressure compaction (>7 MPa) improves strength and durability (Wilaipon, 2009), while binders like cassava starch enhance performance (Duangkham & Thuadaij, 2023; Sindol et al., 2022). Microwave pyrolysis with potato starch yields better combustion than carboxymethyl cellulose (Idris et al., 2021). These findings validate the study's design and highlight the promise of food waste briquettes as clean, renewable fuel.

Production Process

Food waste briquette production follows a sustainable, low-impact process: calamansi and banana peels are chopped, sun-dried to reduce moisture, mixed with or without binders like cassava starch, molded, and further sun-dried to enhance shelf life and combustion (Genuino et al., 2022; Torres & Aberilla, 2024). This eco-friendly method uses biodegradable materials and solar energy, minimizing environmental impact and cost.

Banana peel briquettes show up to 95% lower carbon emissions than traditional charcoal (Torres &

Aberilla, 2024).

Briquettes made from food and agricultural waste exhibit high carbon content, low sulfur and nitrogen, and calorific values ranging from 16.22 to 20.9 MJ/kg (Elsisi et al., 2023; Maia et al., 2014).

Their quality improves with proper binders and drying, as reflected in density, compressive strength, and burn rate (Torres & Aberilla, 2024).

Fuel efficiency is assessed through five key parameters: moisture content, volatile matter, ash content, fixed carbon, and gross calorific value. These determine ignition ease, combustion cleanliness, burn duration, and total energy output. Studies confirm that optimized biomass briquettes yield high energy and low ash, supporting household energy use (Achebe et al., 2018; Dinesha et al., 2019; Heriyanti et al., 2025). Performance depends on moisture, feedstock, density, and technique (Dinesha et al., 2019), affirming the role of briquettes in clean energy and climate solutions (Heriyanti et al., 2025).

RESULTS AND DISCUSSION

The study presents a comprehensive tabulation and comparative analysis of briquettes made from calamansi and banana peels—with and without binders—against commercial wood charcoal, focusing on five parameters: moisture content, volatile combustible matter, ash content, fixed carbon, and gross calorific value. Key findings found in Table 1 and 2, highlight that banana peel briquettes with binder achieve the highest calorific value (4026 cal/g), indicating strong energy efficiency, while calamansi peel briquettes with binder show the lowest ash content (5.0%), suggesting cleaner combustion. Conversely, commercial wood charcoal exhibits higher fixed carbon and energy output, but also higher ash content and environmental costs. These trends underscore the trade-offs between fuel performance and ecological impact, demonstrating how binder use, and raw material type affect overall sustainability.

Table 1. Properties of Calamansi Peel Briquettes

Test/Analysis	Non-Carbonized Calamansi Peels with Binder	Non-Carbonized Calamansi Peels without Binder	Carbonized Wood Charcoal
1. Residual Moisture Content	12.6	8.8	11.70
2. Volatile Combustible Matter	68.1	70.8	36.60
3. Ash Content	5.0	5.7	12.45
4. Fixed Carbon	14.3	14.7	39.25
5. Gross Calorific Value	3622 cal/g 6520 BTU/lb	4002 cal/g 7204 BTU/lb	5015 cal/g 9026 BTU/lb

Table 2. Properties of Banana Peel Briquettes

Test/Analysis	Non-Carbonized Banana Peels with Binder	Non-Carbonized Banana Peels without Binder	Carbonized Wood Charcoal
Residual Moisture Content	9.1	10.1	11.70
Volatile Combustible Matter	63.1	62.2	36.60
Ash Content	8.7	8.5	12.45
Fixed Carbon	19.1	19.2	39.25
Gross Calorific Value	4026 cal/g 7246 BTU/lb	3990 cal/g 7181 BTU/lb	5015 cal/g 9026 BTU/lb

Supporting literature reinforces these findings. Briquettes made from banana peel and bunch waste report calorific values ranging from 5,115 to 6,396 cal/g (Mopoung & Udeye, 2017). Binder addition is shown to reduce ash and moisture content while improving combustion quality (Kumar et al., 2020).

Optimizing binder ratios is essential; lower concentrations (10%) produce better energy output, whereas higher concentrations (15%) may accelerate burn rates (Muliani et al., 2024). Importantly, banana peel briquettes are found to have a 95% lower carbon footprint compared to conventional charcoal (Torres & Aberilla, 2024). However, binder materials are identified as major contributors to environmental impacts, suggesting the need for greener binder alternatives or more energy-efficient production methods to enhance overall sustainability (Torres & Aberilla, 2024).

DISCUSSION AND ANALYSIS

The residual moisture content is a key factor in evaluating the combustion efficiency of biomass briquettes. In this study, non-carbonized briquettes with binder showed a slightly higher moisture content (12.6%) than carbonized wood charcoal (11.7%), likely due to the water-retaining properties of binders like cassava starch. In contrast, briquettes without binder recorded the lowest moisture level (8.8%), indicating improved drying and better fuel performance. Low moisture content is preferred for faster ignition and more efficient combustion. Supporting studies affirm that high moisture levels negatively affect combustion and friability, while low-moisture briquettes offer better impact resistance (Mkini & Bakari, 2015). Binder type also plays a significant role—cassava starch yields lower moisture and faster burning rates than corn starch (Akinbomi et al., 2025), and native wheat starch results in lower smoke and quicker ignition than modified starch (Borowski et al., 2017). However, increasing binder ratios can raise ignition time and volatile matter while decreasing burn rate (Gumban et al., 2024). Optimal binder levels, such as 41.14% cassava starch for banana leaf biochar, are essential for improving briquette quality (Gumban et al., 2024).

Volatile combustible matter (VCM) plays a crucial role in determining the ignition ease and combustion behavior of briquettes. In this study, calamansi peel briquettes—with and without binder—demonstrated significantly higher VCM levels (68.1% and 70.8%, respectively) compared to traditional wood charcoal (36.6%). This indicates that food waste briquettes ignite more easily and release energy rapidly, though their high volatility may lead to shorter burn durations, limiting their use in long cooking tasks. Supporting literature shows that VCM content varies by biomass type—wood waste briquettes range from 11.30% to 26.00% (Shiferaw et al., 2017), palm kernel shells have 17.3% (Sunnu et al., 2021), and binder-rich water hyacinth briquettes exhibit even higher VCM (Carnaje et al., 2018). The use of flash-pyrolysis has also improved the accuracy of VCM assessment (Eklund et al., 1987). While higher VCM enhances ignition, the overall fuel quality also depends on fixed carbon, ash content, and calorific value (Shiferaw et al., 2017; Sunnu et al., 2021; Carnaje et al., 2018).

Ash content, which represents the non-combustible residue left after fuel combustion, is a key indicator of fuel cleanliness and efficiency. In this study, calamansi peel briquettes exhibited significantly lower ash content (5.0%–5.7%) compared to traditional wood charcoal (12.45%), indicating a cleaner burn with less post-combustion waste. This suggests improved suitability for household use by minimizing indoor pollution and cleanup needs. Supporting studies confirm that ash content is a critical quality parameter in biomass briquettes, with values ranging from 1–5% for municipal waste-based briquettes to over 20% for corn cob variants (Zubairu & Gana, 2014). Briquettes made from various agricultural and industrial wastes, such as durian peel, sawdust, and corn cobs, show diverse combustion properties depending on feedstock, density, and binder ratios (Sitogasa et al., 2023; Dinesha et al., 2019). Some of these briquettes even outperform traditional charcoal in calorific value and fixed carbon content (Zubairu & Gana, 2014). However, continued research on emissions and combustion behavior is necessary to optimize their environmental and energy performance (Dinesha et al., 2019).

Fixed carbon represents the solid fraction of fuel that contributes to sustained combustion after volatile matter is removed. In this study, food waste briquettes—derived from calamansi and banana peels—recorded relatively low fixed carbon values (14.3–14.7%) compared to traditional wood charcoal (39.25%). While this suggests shorter burn times and less heat intensity, it also reflects the briquettes' greater biodegradability and reduced environmental impact. This lower carbon content supports faster decomposition and contributes to a lower carbon footprint, aligning with sustainability targets.

Similarly, other studies highlight how fixed carbon content varies with feedstock and production methods. For instance, corn cob briquettes achieved higher fixed carbon levels (72.8–81.9%) than sugarcane bagasse and wood charcoal (Zubairu & Gana, 2014), while pine sawdust and coconut shell briquettes recorded fixed carbon around 55–56%, influenced by carbonization temperature (Dewi et al., 2023). Additionally, the particle size of charcoal and the proportion of binder significantly affect fixed carbon levels and overall briquette performance (Dewi et al., 2020; Hairudin & Yahya, 2025). These findings emphasize the trade-offs between combustion performance and environmental sustainability in alternative briquette fuels.

Calorific value, a key indicator of fuel efficiency, measures the total energy released upon complete combustion. In this study, calamansi peel briquettes without binder achieved the highest calorific value among food waste samples at 4002 cal/g (7204 BTU/lb), with banana peel briquettes following closely. While traditional wood charcoal still leads with 5015 cal/g (9026 BTU/lb), the food waste briquettes offer a respectable energy output, especially considering their renewable and eco-friendly origin. These findings suggest that food waste briquettes are viable alternatives for low- to medium-intensity cooking where sustainability is prioritized. Supporting literature reinforces this potential: banana peel and bunch charcoal briquettes have calorific values between 5,115 and 6,396 cal/g, performing best with 5% clay binder (Mopoung & Udeye, 2017). Microwave pyrolyzed food waste briquettes also matched commercial charcoal performance, particularly when starch binders were used (Idris et al., 2021). Carbonized pineapple peel briquettes reached 25.08 MJ/kg, and mixing water hyacinth with banana or pineapple peels improved calorific values (Mibulo et al., 2023). Groundnut shell briquettes using cassava or banana peel binders produced the highest value at 33.70 MJ/kg (Idah, 2013). These studies underscore that food and agricultural waste briquettes can deliver energy outputs comparable to or exceeding traditional fuels, making them strong candidates for sustainable energy use.

Comparative Efficiency

Food waste briquettes, though slightly lower in energy output than traditional wood charcoal (5015 cal/g), still offer sufficient heat for typical household cooking, with peak values reaching 4026 cal/g. This indicates their viability as cooking fuels in communities looking for affordable, sustainable options. Beyond calorific value, these briquettes present significant environmental advantages. Made from renewable banana and calamansi peels—often discarded as kitchen or market waste—they help divert organic waste from landfills and reduce emissions since their production process avoids carbonization.

Studies support these findings: banana peel and bunch briquettes show calorific values from 5,115 to 6,396 cal/g (Mopoung & Udeye, 2017), and banana leaf briquettes yield 17.7 MJ/kg (Maia et al., 2014). Food waste charcoal briquettes also match the energy content of commercial charcoal (Idris et al., 2021). Environmentally, banana peel briquettes produce 95% fewer CO_2 emissions than conventional charcoal (Torres & Aberilla, 2024) and offer benefits like smokeless combustion and lower ash content (Mopoung & Udeye, 2017). While binders like starch or carboxymethyl cellulose may slightly reduce energy content, they improve durability and form (Idris et al., 2021). Overall, food waste briquettes are not only energy-efficient but also environmentally sound, making them a strong alternative to traditional charcoal.

Environmental Implications

Food waste briquettes offer notable environmental benefits by reducing emissions, managing organic waste, and promoting cleaner household energy use. Their lower fixed carbon content leads to shorter burn times than traditional charcoal but also supports faster decomposition and minimizes carbon buildup. Calamansi and banana peel briquettes produce significantly less ash, contributing to cleaner combustion and reduced indoor air pollution—particularly valuable in poorly ventilated homes. Moreover, repurposing fruit peels into briquettes helps divert organic waste from landfills and presents livelihood opportunities through small-scale briquette production.

Research confirms these advantages: banana peel briquettes emit over 95% less CO_2 compared to conventional charcoal (Torres & Aberilla, 2024), and combining food waste with tree-based biomass improves combustion efficiency (Josiane et al., 2022). These briquettes also burn smokeless and with lower ash content, enhancing indoor air quality (Mopoung & Udeye, 2017). Although they burn for shorter durations—114 minutes for banana peel briquettes and 92 minutes for bunch-based ones—they remain cost-effective, allowing households to reduce cooking energy expenses by up to 70% (Njenga et al., 2013).

CONCLUSION

Based on the comparative analysis of fuel properties, food waste briquettes—particularly those made from banana peels with binder—emerge as the most promising sustainable alternative to wood charcoal. Their relatively high calorific value and low moisture content make them suitable for cooking purposes while ensuring energy efficiency. Meanwhile, briquettes produced from calamansi peels demonstrate excellent performance in terms of ash content, resulting in cleaner combustion and reduced indoor pollution. These findings suggest that both types of food waste briquettes offer valuable environmental and practical benefits, supporting the shift toward renewable and eco-friendly fuel sources.

RECOMMENDATIONS

In light of the study's findings, it is recommended to encourage community-level production of food waste briquettes using locally available materials such as banana and calamansi peels. This initiative can promote sustainable waste management while providing an affordable alternative to traditional cooking fuels. Further research should be conducted to test emission outputs and measure the combustion duration of food waste briquettes to ensure safety, consistency, and energy efficiency in real-life applications. Additionally, future studies may explore other types of food or agricultural waste to broaden the range of viable biomass sources for briquette production. Lastly, it is advisable to propose and support local policies that promote waste-to-fuel programs, particularly in rural and low-income areas, to strengthen environmental protection, energy access, and livelihood development.

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