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Mechanical Design and Performance Evaluation of a Small-Scale Piston-Type Briquetting Machine for Sustainable Densification of Corn Stalk Residues

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Abstract: *The increasing reliance on firewood in rural communities contributes to deforestation and elevated carbon emissions, while vast quantities of agricultural residues such as corn stalks remain underutilized. This study presents the design, development, and performance evaluation of a small-scale piston-type briquetting machine for densifying corn stalk residues into solid biofuel. The system's performance was assessed in terms of briquetting capacity, efficiency, and physical properties of the produced briquettes. Three binder concentrations (10%, 20%, and 30%) were tested. Results showed that 10% binder yielded the highest briquetting capacity at 55.21 kg/hr, while 30% binder achieved the highest efficiency at 86.11%. The briquettes reached a maximum bulk density of 615.34 kg/m³. Economic analysis indicated low material and operational costs, supporting the machine's feasibility for rural deployment. This study highlights the potential of corn stalk briquetting as a sustainable solution for waste-to-energy conversion and decentralized biofuel production.*

Keywords: Briquetting machine; corn stalk residues; biomass densification; biofuel

1. INTRODUCTION

The global energy landscape remains heavily reliant on fossil fuels, which are rapidly depleting and increasingly recognized for their adverse environmental impacts. The continued combustion of petroleum-based fuels has led to a significant rise in greenhouse gas (GHG) emissions, contributing to global warming and environmental degradation. [1] In response, the pursuit of sustainable, renewable energy alternatives has become a critical focus in both industrialized and developing nations. Among these alternatives, biomass, particularly agricultural residues, presents a promising and largely untapped energy source.[2]

In rural regions of the Philippines, firewood remains a primary energy source for cooking and heating. It is estimated that approximately 67% of rural households depend on firewood as their main domestic fuel, contributing to deforestation and increased atmospheric carbon levels. Simultaneously, vast quantities of agricultural biomass waste, such as rice straw, corn stalks, and coconut husks, are generated annually, most of which are either burned in open fields or left to decompose. Such practices not only release harmful pollutants but also represent a significant loss of potential energy. [3]

Corn stalk residues are among the most abundant forms of biomass waste in Philippine farmlands. Following harvest, these residues are often burned in situ, contributing to air pollution and the release of carbon dioxide, methane, and other harmful compounds. Despite their environmental cost, these materials remain underutilized as fuel sources due to their low bulk density, high moisture content, and poor handling characteristics in raw form. Their direct combustion is inefficient and poses challenges in transport, storage, and emission control. [4]

Briquetting, compacting biomass into dense, uniform blocks, offers a practical solution to these challenges. Through mechanical densification, briquetting increases the energy density of biomass, reduces its volume, and improves combustion characteristics. Briquettes also facilitate easier storage, handling, and transportation, making them a suitable substitute for traditional solid fuels like firewood and coal. [5]Among the various briquetting technologies, piston-type presses are particularly suitable for small-scale, decentralized applications due to their mechanical simplicity, moderate cost, and adaptability to local fabrication methods.

To address the environmental and socio-economic challenges associated with agricultural biomass waste, this study presents the design and performance evaluation of a small-scale piston-type briquetting machine specifically intended for corn stalk residues. The goal is to provide an accessible and sustainable solution for rural communities, enabling farmers to convert agricultural waste into value-added biofuel.

The study aimed to: (1) design and develop a small-scale piston press briquetting machine; (2) produce briquettes using locally sourced corn stalks; (3) evaluate the machine's performance in terms of briquetting capacity and efficiency; and (4) assess key physical properties of the resulting briquettes, including moisture content and bulk density. These performance indicators are essential in determining the viability of briquettes as a fuel alternative, particularly in rural settings where ease of use, affordability, and durability are critical.

This research is significant in promoting cleaner energy practices and supporting the livelihoods of rural farmers. By diverting agricultural waste from open field burning to a more productive and environmentally sound use, the study aligns with broader national and global efforts toward sustainable development, rural energy access, and climate change mitigation. [6]Moreover, the machine's design emphasizes simplicity, low cost, and operational characteristics, which are essential for deployment in low-resource agricultural communities.

The scope of the study was limited to the experimental evaluation of corn stalk residues as feedstock for briquette production. Parameters such as briquetting capacity (kg/hr), briquetting efficiency (%), moisture content (%), and bulk density (kg/m³) were measured under controlled conditions using varying binder concentrations. The results provide a foundation for further optimization and potential scale-up, but do not yet include economic analysis, emission profiling, or long-term durability testing of the briquettes.

By bridging the gap between biomass availability and practical energy use, this study contributes to the advancement of small-scale renewable energy technologies tailored to local agricultural contexts. [7]

2. RELATED WORK

2.1 Design and fabrication of small-scale piston press briquetting machine

The design and fabrication of briquetting machines are pivotal in converting agricultural residues into viable energy sources. Piston press briquetting machines have garnered attention for their ability to produce high-density briquettes suitable for combustion. These machines operate by compressing biomass under high pressure without the need for binders, relying on the natural lignin content of the biomass to act as a binding agent. [6]

In designing such machines, considerations include the selection of materials, the design of the compression chamber, and the mechanism for applying pressure. Studies have emphasized the importance of using locally available materials to reduce costs and ensure ease of maintenance. Moreover, the incorporation of replaceable molds can enhance the machine's versatility, allowing them to produce briquettes of varying sizes and shapes. [8]

The fabrication process typically involves machining, welding, and assembly of components such as the frame, piston, crankshaft, and flywheel. Ensuring precise alignment and tolerances is crucial to minimizing friction and wear, thereby enhancing the machine's durability and performance. [9]

2.2 Production of Briquettes Using Corn Stalk

Corn stalks, a byproduct of maize cultivation, represent a significant source of lignocellulosic biomass. Their utilization in briquette production not only provides an alternative energy source but also addresses issues related to waste management and environmental pollution. [4]

The process of converting corn stalks into briquettes involves several steps: collection, drying, size reduction, and compaction. Drying is essential to reduce the moisture content to optimal levels (typically around 10-15%) to ensure efficient combustion and prevent microbial degradation. Size reduction, achieved through chopping or grinding, increases the surface area and facilitates uniform compaction. [4]

The compaction process in piston press machines applies high pressure to the prepared biomass, resulting in dense and durable briquettes. Studies have demonstrated that corn stalk briquettes exhibit satisfactory combustion properties, making them suitable for domestic and industrial applications.[10]

2.3 Performance evaluation of the small-scale piston press briquetting machine

Evaluating the performance of briquetting machines is essential to determine their efficiency, productivity, and suitability for specific biomass types. Key performance indicators include briquetting capacity, energy consumption, and the quality of the produced briquettes.

Briquetting capacity refers to the amount of biomass that can be processed into briquettes over a given time. Factors influencing capacity include the machine's design, operating conditions, and the properties of the feedstock. Energy consumption is another critical parameter, with efficient machines consuming less energy per unit of briquette produced. [11]

The quality of briquettes, assessed through parameters such as density, durability, and combustion characteristics, provides insights into the machine's effectiveness. [12] For instance, studies have shown that piston press briquetting machines can produce briquettes with high bulk density, indicating effective compaction and suitability for storage and transport. [13]

Moreover, the machine's operational stability, ease of maintenance, and adaptability to different biomass types are crucial for its widespread adoption, especially in rural settings where technical support may be limited. [14]

2.4 Physical Properties of Biomass Briquettes: Moisture Content and Bulk Density

The physical properties of biomass briquettes significantly influence their handling, storage, and combustion efficiency. Two critical parameters in this regard are moisture content and bulk density. [9]

Moisture content affects the combustion efficiency and calorific value of briquettes. High moisture levels can lead to incomplete combustion, increased smoke production, and lower energy output. Optimal moisture content for briquettes is generally between 10-15%. Achieving this requires proper drying of the biomass before compaction and, in some cases, post-production drying of the briquettes. [15]

Bulk density, defined as the mass of briquettes per unit volume, impacts storage and transportation logistics. Higher bulk density implies more energy content per unit volume, making briquettes more economical to store and transport. Studies have shown that densification through piston press machines can significantly increase the bulk density of biomass, with values ranging from 450 to 700 kg/m³, depending on the feedstock and compaction pressure. [15]

3. METHODOLOGY

This study was conducted to design, develop, and evaluate the performance of a small-scale piston-type briquetting machine using corn stalk residues. The methodological framework was structured to address the four key objectives.

The process flow in Figure 1 illustrates the systematic approach employed in the design, fabrication, and evaluation of a small-scale piston-type briquetting machine. It begins with establishing key design considerations, which are informed by the physical properties of the biomass feedstock (e.g., corn stalks) and the characteristics of the binding agents. These parameters guide the component sizing and design analysis phase, where machine elements are dimensioned, and material strength and load calculations are performed to ensure structural integrity and operational efficiency. The finalized design is then fabricated, followed by machine testing to verify mechanical functionality. Data gathering is conducted during performance trials, where the machine is tested using different binder ratios to produce briquettes. Key performance indicators such as briquetting capacity, efficiency, moisture content, and bulk density are measured. The final stage involves evaluating these data to assess machine performance. If results fall short of expectations, design adjustments are made, creating a feedback loop that enhances system optimization.

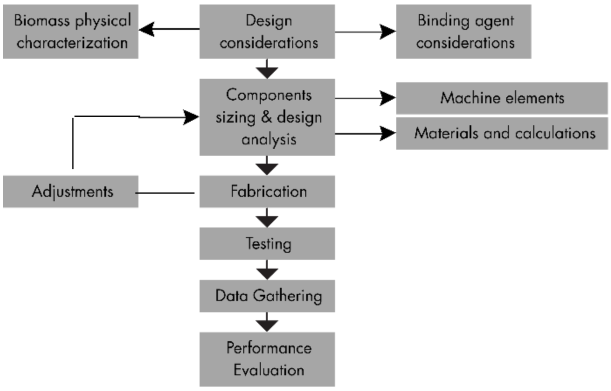

Fig. 1. Process flow

3.1 Design Considerations and Components

The design and fabrication of the briquetting machine were carried out with the goal of creating a low-cost, small-scale, and locally manufacturable piston-type press capable of compacting agricultural residues, specifically corn stalks, into dense, transportable briquettes. The design process was guided by a set of functional requirements, including ease of operation, mechanical reliability, and compatibility with locally available materials and power sources. Initial considerations included the physical characteristics of the biomass, desired output dimensions, compressive force requirements, and expected throughput. These inputs informed the engineering calculations for component sizing, particularly the piston, die chamber, crankshaft, and structural frame. [10]

Mechanical transmission was achieved through a crank-slider mechanism powered by a 1.0 horsepower electric motor. Torque and speed reduction were facilitated using pulleys and V-belts, designed to optimize the force applied to the biomass during compaction. The piston and compression chamber were fabricated from stainless steel to withstand repeated loads and to minimize corrosion and wear. The frame was constructed using welded mild steel angle bars to provide structural rigidity while keeping the machine lightweight and portable. [13]

A CAD model was developed to visualize the mechanical layout and ensure the spatial compatibility of all components. Critical components such as the crankshaft, connecting rod, piston head, and die were dimensioned and machined with precision to minimize misalignment and mechanical losses during operation. Once fabricated, the machine was assembled and subjected to initial dry-run testing to evaluate the synchronization of moving parts, confirm stroke consistency, and detect mechanical imbalances. Adjustments were made as necessary to improve performance and ensure operational stability under load conditions.

The final prototype had an estimated weight of 73.7 kg and was designed for bench-level operation, making it suitable for smallholder applications. Its modular construction allows for easy maintenance and component replacement. The resulting design reflects a balance between engineering efficiency, cost-effectiveness, and appropriateness for rural deployment, forming the foundation for subsequent performance evaluation using corn stalk biomass.

3.2 Briquette Production Using Corn Stalk Residues

The production of briquettes commenced with the preparation of corn stalk residues, which served as the primary biomass feedstock for the study. Corn stalks were collected post-harvest from nearby agricultural fields and subjected to a series of pre-treatment processes to ensure uniformity and optimize compaction. Initially, the stalks were air-dried under ambient conditions to reduce their moisture content to within the optimal range of 10 - 15%, suitable for effective briquetting and combustion. Following drying, the biomass was mechanically shredded to reduce particle size to ≤2 mm, a critical step that increases surface area, improves packing density, and facilitates uniform compaction during briquette formation.

To improve the mechanical strength and integrity of the briquettes, cassava starch was employed as a natural binding agent. It was selected for its local availability, cost-effectiveness, and proven adhesive properties in biomass densification applications. The binder was prepared by dissolving the cassava starch in hot water to achieve a gelatinized consistency, then thoroughly mixed with the shredded corn stalks. Three different binder-to-biomass ratios, 10%, 20%, and 30% by weight, were prepared to examine the influence of binder content on briquette quality and machine performance.

Table 1. Binder proportions

Binder %	Corn stalk %	Proportion
10	100	100:10
20	100	100:20
30	100	100:30

Once homogenized, the mixture was immediately fed into the hopper of the piston-type briquetting machine. The machine's reciprocating piston compacted the biomass-binder mixture into cylindrical briquettes through a fixed-diameter die. The extruded briquettes were collected and air-dried for 24 hours to reduce surface moisture and allow for physical stabilization before testing. This method ensured consistency in feed preparation, briquette dimensions, and drying conditions, all of which are essential for accurate performance evaluation and comparative analysis across treatment levels.

3.3 Determination of Physical Properties of Briquettes

Moisture content was evaluated using the wet basis method. Samples were weighed before and after the oven, drying at 105°C for 24 hours:

$$MC = \frac{(WW - DW)}{WW} x\ 100\% \quad (1)$$

Where:

- MC = Moisture content (%)
- WW = Initial wet weight of the briquette (g)
- DW = Dry weight after drying (g)

Each treatment was replicated thrice, and the mean value was computed.

Bulk density was determined by using water displacement for volume measurement:

$$\rho = \frac{M}{V} \quad (2)$$

Where:

- ρ = Bulk density (kg/m³)
- M = Mass of the briquette (kg)
- V = Volume of the briquette (m³)

High bulk density values indicate improved compaction, transportability, and storage efficiency.

3.4 Experimental Design and Statistical Analysis

A Randomized Complete Block Design (RCBD) was used with three binder treatments and three replications. The data collected for capacity, efficiency, moisture content, and bulk density were subjected to Analysis of Variance (ANOVA). Significance was evaluated at 5% and 1% levels using F-tests, and treatment means were compared using appropriate post-hoc tests when required.

4. RESULTS AND DISCUSSIONS

This section presents and analyzes the results of the study in accordance with the four specific objectives: (1) design and fabrication of the piston-type briquetting machine, (2) production of briquettes using corn stalk residues, (3) performance evaluation of the machine, and (4) characterization of the physical properties of the briquettes.

4.1 Design and Fabrication of the Briquetting Machine

The small-scale piston-type briquetting machine was designed and fabricated based on functional requirements, mechanical calculations, and locally available materials.

Table 2. List of materials

Materials	Quantity (pcs)
Electric motor (1hp)	1
V-belt	2
V-pulley (10"x1")	1
V-pulley (8"x1")	1
V-pulley (3"x1")	2
Mild steel shaft (16mm x 50cm)	1
Mild steel shaft (20mm x 50cm)	1
Angle bar (30 x 30mm x 6m) 4mm thickness	3
Mild steel hollow pipe (50mm x 1m Inside Diameter)	1
Mild steel hollow pipe (25mm x 1m Inside Diameter)	1
Mild steel ram (50mm x 300mm)	1
Pillow block bearing	6

The selection of materials for the machine components, particularly the ram and compression cylinder, prioritized durability and operational efficiency. Stainless steel was utilized for these critical parts due to its superior resistance to corrosion and its relatively low coefficient of friction, which serves to minimize energy losses during compaction and reduce material wear over time. To ensure reliability and optimal performance, a series of functional tests and mechanical adjustments were conducted following initial assembly. Moreover, the machine was designed with user-centered maintainability in mind. The compression chamber and die assembly were fitted with detachable fasteners, specifically, bolts and nuts, to facilitate straightforward disassembly. This feature enables efficient cleaning and removal of residual biomass post-operation, thereby minimizing the risk of contamination, mechanical blockage, or material degradation between successive briquetting cycles.

The final prototype had an estimated total weight of 73.7 kg and was powered by a 1.0 hp electric motor. The machine utilized a crank-slider mechanism with a 35 mm die diameter and was configured for single-operator use in rural or decentralized settings.

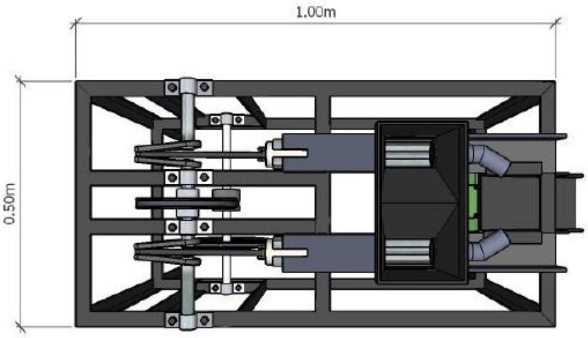

Fig. 2. Top view of the machine

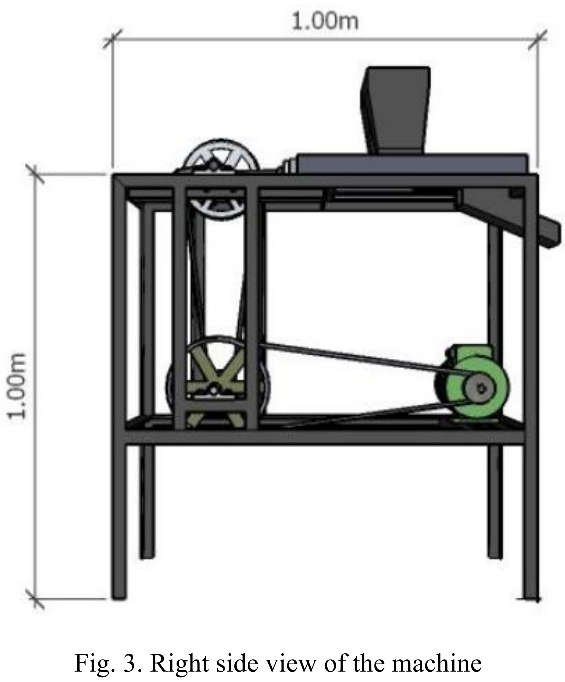

Fig. 3. Right side view of the machine

Preliminary dry-run testing confirmed smooth mechanical operation, proper alignment of rotating and reciprocating parts, and effective compaction during load trials.

Table 3. Summary of Mechanical Design and Transmission Calculations for the Briquetting Machine

Parameter	Value	Unit	Remarks
Designed Power	969.8	W	Based on compression force and operating requirements
Torque (Main Shaft)	110.83	N·m	Derived from motor and pulley system configuration
Speed of Pulley 2	524	rpm	Intermediate pulley speed
Speed of Pulley 3	197	rpm	Final output speed for compaction
Total Belt Length (Belt 1 & 2)	1,838.43	mm	Calculated before correction factor applied
Total Belt Length (Belt 2 & 3)	1,554.31	mm	
Corrected Belt Length (Standard – Belt 1 & 2)	1,798.32	mm	Based on PAES 301:2000 belt correction factor (0.96)
Arc of Contact (Pulley 1)	163.82	degrees	Influences power transmission efficiency
Arc of Contact (Pulley 2)	166.34	degrees	
Belt Correction Factor	0.96	–	Standardized for tension and arc of contact
Center Distance (Pulley 1–2)	633.86 (approx. 634)	mm	Spacing optimized for proper belt tension
Center Distance (Pulley 2–3)	665.52 (approx. 666)	mm	
Belt Speed (D1, N1)	417.83 / 6.96	m/min / m/s	Input pulley speed
Belt Speed (D2, N2)	125.11 / 2.085	m/min / m/s	Output pulley speed
Material for Shafts	Mild Steel	–	Allowable τ = 50 N/mm²; σ = 120 N/mm²
Diameter of Shaft 1	12.16 (rounded to 16)	mm	Increased for safety and manufacturability
Diameter of Shaft 2	16.85 (rounded to 20)	mm	
Total Weight of Machine	73.7	kg	Lightweight and portable for rural use

The transmission system was designed to deliver sufficient torque and speed reduction for effective biomass compression while maintaining energy efficiency. The system uses a multi-pulley configuration to reduce the input motor speed (presumably ~1400 rpm) down to 197 rpm at the output shaft, ensuring the piston receives adequate mechanical leverage for compaction.

Belt lengths and arc of contact were calculated following PAES 301:2000 standards to ensure proper tension, minimal slippage, and optimal power transfer. The use of a correction factor of 0.96 accounts for deviations due to contact arc and improves belt life and reliability. The center distances were selected to maintain proper alignment and avoid excessive belt deflection or over-tensioning.

The belt speeds, 6.96 m/s at the input and 2.085 m/s at the output, fall within the recommended range for V-belt drives in medium-duty applications. These values help minimize energy loss and mechanical vibrations while maintaining steady operation.

For the shaft design, mild steel was chosen due to its availability and mechanical suitability. The calculated shaft diameters (12.16 mm and 16.85 mm) were conservatively increased to 16 mm and 20 mm respectively to enhance safety margins, account for fabrication tolerances, and prevent failure under cyclic loading conditions.

The mechanical design ensures that the system can generate sufficient compaction force while maintaining robustness, manufacturability, and adaptability for small-scale rural deployment.

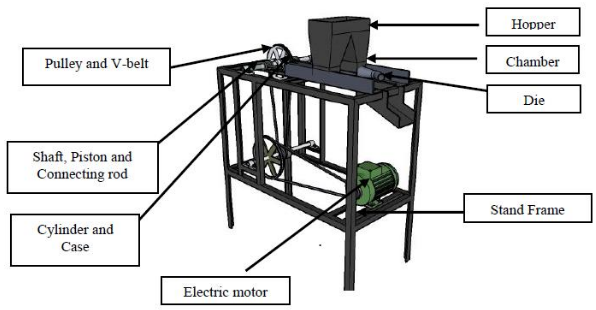

Fig. 4. Isometric view of piston press briquetting machine

Fig. 5. Actual Photo of Piston Press Briquetting Machine

The final assembly allowed consistent feeding, reliable piston motion, and safe briquette extrusion. Modularity in design supported ease of maintenance and potential scalability.

4.2 Briquette Production Using Corn Stalk Residues

The corn stalk biomass was successfully processed into briquettes using the fabricated machine. Uniform particle size (≤2 mm) and controlled moisture content (~13%) were achieved through pre-processing. Three binder concentrations – 10%, 20%, and 30% by weight of cassava starch, were tested to assess their effect on briquette quality and machine performance.

Visual inspection revealed that all binder treatments produced briquettes with adequate structural integrity and cohesion. Briquettes produced with higher binder concentrations appeared denser and exhibited improved surface smoothness and resistance to cracking.

4.3 Performance Evaluation of the Briquetting Machine

The machine's performance was quantified in terms of briquetting capacity (kg/hr) and briquetting efficiency (%). Table 4 presents the average results across three replicates for each binder treatment.

Table 4. Briquetting Capacity

Binder %	Briquetting Capacity, (kg/hr) Rep. I	Rep II	Rep III	Total Treatment (T)	Treatment Mean
10	62.24	50.51	52.89	165.64	55.21
20	23.23	24.78	25.00	73.01	24.34
30	30.60	28.48	26.81	85.89	28.33
Rep total (R)	116.07	103.77	104.70		
Grand total (G)				324.54	
Grand mean					35.962

The highest mean capacity was achieved at 10% binder, averaging 55.21 kg/hr, while 20% and 30% treatments recorded 24.34 kg/hr and 28.33 kg/hr, respectively. The grand mean across all treatments was 35.96 kg/hr.

The results indicate that lower binder content enhances production capacity due to reduced mixture viscosity and internal friction, allowing smoother piston movement and faster compaction cycles. However, the unexpectedly lower capacity at 20% compared to 30% may be attributed to nonlinear compaction behavior. At this intermediate level, the mixture may have exhibited poor flowability or inconsistent cohesion, leading to irregular piston loading and less efficient strokes. In contrast, the 30% mixture may have been more cohesive, resulting in steadier operation despite increased drag.

These results highlight that binder percentage does not always affect performance in a linear fashion, experimental validation remains crucial. For practical deployment, a 10% binder ratio is recommended for maximizing throughput in small-scale, rural applications. However, higher binder levels may still be preferred when briquette durability or structural integrity is prioritized for handling and transport.

Table 5. ANOVA of Briquetting Capacity

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5 %	1 %
Replication	2	31.27	15.64	1.14^{ns}	19	99
Treatment	2	1678.47	839.24	61.37 *	19	99
Error	4	54.70	13.68		19	99
Total	8	1764.45				

ns = not significant
* = significant

In contrast, the highest briquetting efficiency was recorded at the 30% binder level, averaging 86.11%, followed by 20% (80.11%) and 10% (70.45%). Higher binder content enhances particle bonding, leading to more effective material compaction and lower rejection or loss rates during extrusion.

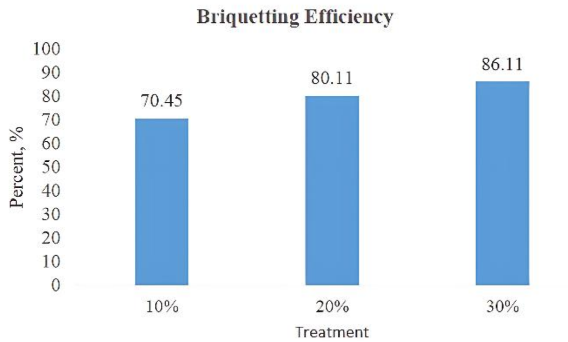

Fig. 6. Graphical representation of the briquetting efficiency

Statistical analysis via ANOVA revealed a significant difference ($p < 0.05$) in briquetting capacity across treatments but no significant difference in efficiency, suggesting that binder concentration affects production rate more strongly than conversion yield.

4.4 Physical Properties of Biomass Briquettes

The quality of the briquettes was evaluated in terms of moisture content and bulk density, two critical factors that influence fuel performance, transportability, and storability.

Table 6. Moisture Content

Binder %	Briquetting Capacity, (kg/hr) Rep. I	Rep II	Rep III	Total Treatment (T)	Treatment Mean
10	13.13	12.50	13.89	39.52	13.17
20	12.50	13.68	14.21	40.39	13.46
30	13.24	13.11	14.29	40.64	13.54
Rep	38.8	39.2	42.3		

total (R)	7	9	9		
Grand total (G)				120.55	
Grand mean					13.39

Moisture content was fairly consistent across all treatments, ranging from 13.17% to 13.54%, with no statistically significant differences ($p > 0.05$). This uniformity was likely due to similar drying conditions and feedstock handling. These values fall within the optimal range (10–15%) for efficient combustion and storage stability, as recommended in biomass fuel literature.

Table 7. ANOVA of Moisture Content

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5%	Tabular F 1%
Replication	2	2.46	1.23	5.64^{ns}	19	99
Treatment	2	0.23	0.11	0.53^{ns}	19	99
Error	4	0.87	0.22		19	99
Total	8	3.57				

ns = not significant

Bulk density increased with binder content, ranging from 551.97 kg/m³ (10% binder) to 615.34 kg/m³ (30% binder). Higher binder concentration promotes better particle cohesion and reduces internal voids during compaction, leading to denser briquettes. Though the differences were not statistically significant at the 5% level, the trend suggests that adjusting binder ratios can help tailor briquette density for specific transport and combustion requirements.

Table 8. Bulk Density

Binder %	Briquetting Capacity, (kg/hr) Rep.I	Rep II	Rep III	Total Treatment (T)	Treatment Mean
10	600.00	576.00	479.91	1655.91	551.97
20	581.40	575.95	600.60	1757.95	585.98
30	616.00	629.68	600.34	1846.02	615.34
Rep total (R)	1797.43	1781.63	1680.85		
Grand total (G)				5259.91	
Grand mean					584.43

Table 9. ANOVA of Bulk Density

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5%	Tabular F 1%
Replication	2	2665.47	1332.73	0.86^{ns}	19	99
Treatment	2	6034.48	3017.24	1.95^{ns}	19	99
Error	4	6177.89	1544.47		19	99
Total	8	14877.84				

ns = not significant

These density values fall within the desirable range for commercial-grade briquettes and suggest that the developed machine can produce solid fuel products suitable for rural households and small-scale industries.

4.6 Power Consumption and Bill of Materials

The projected energy consumption for operating the briquetting machine using a 1.0 horsepower electric motor is estimated at approximately 2,178.42 kilowatt-hours per year. This projection is based on typical daily usage patterns and continuous operation under load conditions. Correspondingly, the annual electricity cost is calculated to be around PHP 13,342.21, assuming prevailing residential or agricultural electricity rates. These values offer practical insight into the operational energy demands of the system and reinforce its economic feasibility for rural or off-grid applications, especially when compared to conventional fuel processing methods that often require more labor or fuel input. This cost-efficiency, combined with the machine's productivity, highlights its potential as a sustainable alternative for community-scale biomass densification initiatives.

The total investment cost for a single unit of the briquetting machine was estimated at PHP 13,880.00, comprising PHP 9,380.00 for materials and PHP 4,500.00 for labor. This cost structure reflects the use of locally available components and fabrication methods, underscoring the machine's affordability and suitability for small-scale deployment in rural settings. The relatively low capital requirement enhances its accessibility for community-based livelihood programs and decentralized bioenergy production.

5. CONCLUSIONS AND RECOMMENDATIONS

This study presented the design, development, and performance evaluation of a small-scale piston-type briquetting machine intended for densifying corn stalk residues into solid biofuel. The machine demonstrated functional performance, achieving a maximum briquetting capacity of 55.21 kg/hr at a 10% binder concentration, while a 30% binder resulted in the highest briquetting efficiency of 86.11%. The briquettes produced exhibited a maximum bulk density of 615.34 kg/m³, indicating favorable compressibility and handling characteristics.

Cost and energy analyses revealed that the system is both economically and operationally viable. The total fabrication cost was PHP 13,880.00, while annual energy consumption was estimated at 2,178.42 kWh, incurring an annual operating cost of PHP 13,342.21. These findings highlight the potential of the machine as a low-cost, decentralized solution for converting agricultural residues into renewable fuel, with implications for reducing environmental pollution and enhancing rural energy access.

To advance the system's development and application, the following recommendations are made:

1. Examine different binder materials and concentrations to optimize both production capacity and briquette durability.

2. Implement community-based testing to evaluate real-world usability, performance stability, and user feedback.
3. Assess the feasibility of scaling the machine for semi-commercial or cooperative-level operations.
4. Conduct a life cycle assessment to quantify emission reductions and sustainability benefits compared to open field burning and firewood usage.

These recommendations support the continued improvement and wider adoption of briquetting technologies for sustainable rural development.

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