

## DEVELOPMENT AND PERFORMANCE EVALUATION OF A 3-IN-1 PULVERIZING, MIXING AND BRIQUETTING SYSTEM FOR SUSTAINABLE BIOMAS FUEL PRODUCTION IN INDUSTRIAL AND COMMUNITY APPLICATIONS

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### ABSTRACT

The growing demand for renewable energy and sustainable resource utilization emphasizes the need for efficient technologies that convert agricultural residues into alternative solid fuels. Conventional biomass processing involves separate pulverizing, mixing, and briquetting operations, resulting in increased energy consumption, extended processing time, and higher operational costs. This study presents the design, development, and performance evaluation of an integrated 3-in-1 system that consolidates these functions into a single unit powered by a unified drive mechanism, enhancing portability, cost efficiency, and ease of maintenance. The machine features a two-stage pulverizing chamber for size reduction, a mixing unit for binder and moisture integration, and a screw-extruder briquetting assembly for densified fuel production. Performance testing showed functional efficiencies of 94.5% for pulverizing, 98% for mixing, and 95% for briquetting, with an overall system efficiency of 87.98%. Measured throughput capacities reached 28 kg/hr for pulverizing, 42.8 kg/hr for mixing, and 27 kg/hr for briquetting, with process flow constrained at the briquetting stage. Results demonstrate that the integrated system significantly streamlines biomass briquette production, reduces operational costs, and provides a scalable solution for agricultural waste valorization. Its application extends to small-scale industries and community-based energy programs, supporting renewable energy generation and contributing to sustainable industrial and rural development.



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### I. INTRODUCTION

The global transition toward sustainable energy systems has intensified the search for efficient, low-cost, and environmentally sound alternatives to fossil fuels. Biomass-based solid fuels, particularly briquettes formed from agricultural waste, are increasingly viewed as a practical and accessible solution to energy insecurity, especially in rural and developing regions [1]. These briquettes are compact, easy to handle, and produce cleaner combustion compared to traditional firewood or coal, making them ideal for household and small-scale industrial applications. Moreover, the production of briquettes from agricultural waste is economical because it involves conversion of waste to wealth, providing an alternative and renewable source of energy and at the same time minimizing the environmental nuisance which makes the environment unclean [2]. Agricultural waste such as coconut shells, cacao husks, corn cobs, rice hulls, and charcoal dust is abundantly available in many tropical countries. In the Philippines alone, the coconut industry spans millions of hectares, generating significant quantities of lignocellulosic biomass that often remains underutilized [3].

For instance, approximately 77% of a cacao pod's mass consists of husks that are typically discarded after bean extraction [4]. These waste materials hold immense potential for energy generation if properly processed and densified into briquettes [5], [6]. Despite the potential, existing briquetting systems are often cost-prohibitive or logistically impractical for decentralized, community-level applications. Most systems require separate machines for pulverizing, mixing, and briquetting, each operated independently with its own motor and control mechanism. This setup results in high energy consumption, greater labor demands, and larger operational footprints, ultimately limiting scalability and accessibility for low-resource users [7], [8]. Furthermore, transferring material manually between units introduces additional inefficiencies and potential contamination. To address these challenges, this study introduces a compact and integrated 3-in-1 machine that consolidates pulverizing, mixing, and briquetting processes into a single, modular system. The machine is driven by one motor and mounted on a unified frame to reduce operational complexity, energy consumption, and cost. This innovation is particularly tailored for rural communities, farmer cooperatives, and small-scale entrepreneurs who require affordable and user-friendly solutions for converting waste into value-added solid fuel. The objectives of this study are threefold: (1) to design and fabricate a 3-in-1 biomass briquetting device using locally available materials, (2) to evaluate the system's efficiency and production capacity, and (3) to demonstrate the feasibility of using the machine for sustainable solid fuel production at the community level. This work supports broader environmental and socio-economic goals, including waste valorization, renewable energy deployment, and inclusive technological innovation.

## II. MATERIALS AND METHODS

### II.1 DESIGN OF THE 3-IN-1 INTEGRATED SYSTEM

The machine was designed to deliver seamless integration of pulverizing, mixing, and briquetting functions into a single system. A key design criterion was minimizing the device's physical footprint while maximizing functional efficiency. The entire system is driven by a single-phase electric motor, reducing the energy cost associated with separate motors for each unit. All components are mounted on a welded steel frame and are designed for both fixed and detachable use, enhancing the device's adaptability to various operational conditions. Considerations were given to ergonomics, safety features, local material availability, and ease of fabrication and maintenance [9], [10]. The overall layout of the integrated 3-in-1 integrated system is illustrated in Figure 1, showing the alignment and placement of each unit on a compact frame to enhance material flow and operational efficiency. The internal structure and components of this section are presented in Figure 2, highlighting the section view that delineates how each functional unit is connected.

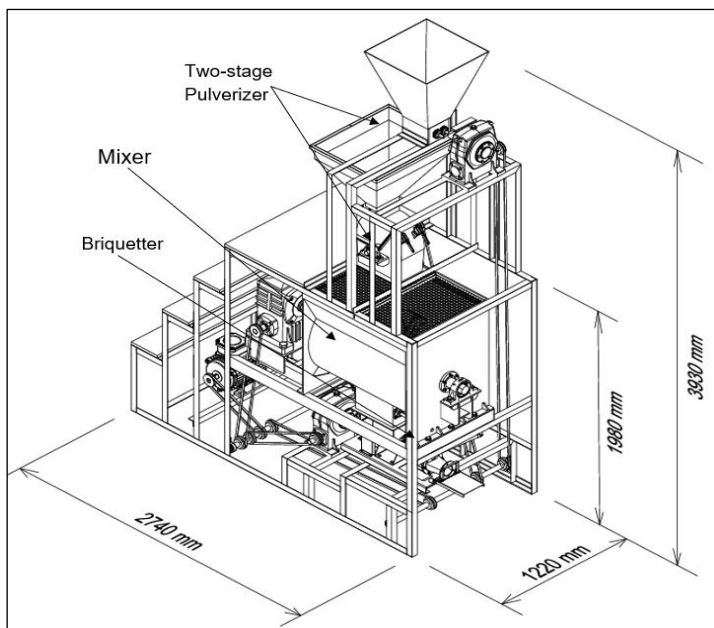


Figure 1: The 3-in-1 Integrated System.  
Source: Authors, (2026).

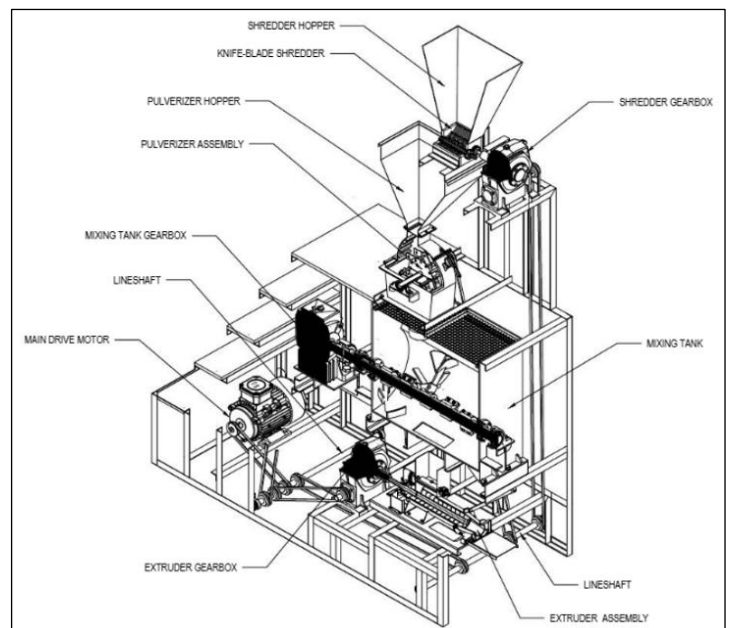


Figure 2: Section View of the 3-in-1 Integrated System.  
Source: Authors, (2026).

### II.2 PRINCIPLE OF OPERATION

The machine follows a vertically aligned workflow where gravity assists material transfer from one stage to the next. The process begins with size reduction of raw agricultural biomass in the two-stage pulverizing unit, which includes a knife-blade shredder for coarse materials and a hammer mill for finer grinding [11]. The pulverized material then flows into the mixing unit, where it is combined with a binder (molasses or starch) and water. The mixer, using a paddle-type blade, ensures uniform distribution of the binder, yielding a homogenous mass with optimal viscosity [12], [13]. Finally, the mixture is fed into the briquetting unit, where a screw extruder compresses it into dense briquettes. The die at the extruder's output defines the briquette's final shape and size. The entire operation is powered through a system of belts and pulleys regulated by a Variable Frequency Drive (VFD), which allows for real-time speed and torque adjustments.

## II.3 FABRICATION AND ASSEMBLY

The fabrication of the 3-in-1 pulverizing, mixing, and briquetting system was undertaken using readily available local materials and standard workshop tools. The main structural frame was constructed from medium-carbon steel angular bars, selected for their strength, ease of fabrication, and cost-effectiveness. Each of the three core units—pulverizer, mixer, and briquetter—was designed as a detachable module, allowing for individual assembly, maintenance, or potential future upgrades. The pulverizing unit consisted of a knife-blade shredder and a hammer mill, both driven by a geared mechanism supported on pillow blocks to minimize vibration during operation. This dual arrangement allows materials like coconut shells or cacao husks to undergo either coarse or fine grinding depending on their physical characteristics. The mixer was constructed as a paddle-type system housed within a cylindrical drum. Its shaft was powered via belts and pulleys from the central motor, transmitting torque through a dedicated gearbox with a 1:40 ratio. The mixing chamber includes a bottom outlet to discharge blended material, and a top cover to contain dust and improve safety. The briquetting unit featured a screw extruder enclosed within a barrel. A hopper located above the barrel received the mixed material, which was then compacted by the rotating screw and forced through a shaped die at the outlet. This assembly ensures consistent briquette size and density. All three units were bolted to the main angular frame, and their alignment was carefully calibrated to ensure smooth flow of material from one unit to the next. A Variable Frequency Drive (VFD) control system was installed to regulate motor speed, torque distribution, and to enhance operational flexibility. The VFD and motor are mounted within a protected enclosure with LED indicators and speed control potentiometers for user interface. Additionally, a lightweight platform and railings were fabricated to provide operator access and improve safety during feeding and observation. The final structure was painted for corrosion resistance and labeled for easier identification of controls and components.

## II.4 PERFORMANCE EVALUATION

The performance of the fabricated 3-in-1 system was assessed through a series of tests measuring both the material efficiency of each unit and the throughput capacity of the integrated machine. Each module was tested independently and then evaluated as part of the fully assembled system. During the evaluation, coco shell (50%) and cacao pods (50%) were used and constitutes 70% of raw materials, cassava starch as binder (20%), and water (10%) for a 10kg batch size.

### II.4.1 Efficiency Calculation

Efficiency refers to the proportion of input material that is successfully processed into usable output. The efficiency of each subunit was calculated using the following general formula:

$$\text{Efficiency (\%)} = \frac{\text{Input Mass, } M_i \text{ (kg)}}{\text{Output Mass, } M_o \text{ (kg)}} \times 100 \quad (1)$$

The overall system efficiency, OE, of the integrated machine was determined as the product of the decimal equivalents of each subunit's efficiency:

$$OE = PE \times ME \times BE \quad (2)$$

Where:

*PE* is the pulverizing efficiency;

*ME* is the mixing efficiency; and,

*BE* is the briquetting efficiency.

### II.4.2 Throughput Capacity

Throughput capacity was defined as the amount of material processed per unit of time, expressed in kilograms per hour (kg/hr). Capacities for each functional unit were computed using the following equations:

$$\text{Pulverizing Capacity, PC} = \frac{\text{Quantity of Pulverized Material (kg)}}{\text{Processing Time (hrs)}} \quad (3)$$

$$\text{Mixing Capacity, MC} = \frac{\text{Batch size (kg)}}{\text{Mixing Time (hrs)}} \quad (4)$$

$$\text{Briquetting Capacity, BC} = \frac{\text{Quantity of Briquettes (kg)}}{\text{Processing Time (hrs)}} \quad (5)$$

The overall capacity, OC, of the integrated machine was governed by the slowest-performing unit and was calculated as:

$$\text{Overall Capacity, OC} = \min(\text{PC, MC, BC}) \quad (6)$$

Measurements were conducted using a digital weighing scale and a stopwatch. The mass of input and output materials, as well as the time taken for each operation, were recorded under consistent environmental and operating conditions. This systematic testing ensured the reliability of the device's functional performance and its suitability for continuous use in real-world applications.

## III. RESULTS AND DISCUSSIONS

### III.1 FABRICATED SYSTEM DESCRIPTION

Figure 3 shows the complete integrated system which demonstrated high structural integrity and mechanical coordination. Each component is strategically aligned to facilitate the downward flow of materials, enhancing process efficiency.



Figure 3: 3-in-1 Pulverizing, Mixing, and Briquetting System.

Source: Authors, (2026).

The two-stage pulverizer, as shown in Figure 4, effectively reduced raw agricultural materials like coconut shells and cacao pods to fine, uniform particles, and its dual configuration allows materials to bypass the shredder if already fragmented. The paddle-type mixer, as shown in Figure 5, produced a consistent mixture by thoroughly incorporating binders and water into the pulverized biomass. This consistency is vital for successful extrusion, ensuring uniform shape and density in the final product. The screw-type briquetter, shown in Figure 6, formed cylindrical briquettes with minimal human intervention and without jamming, highlighting the efficiency of the screw-barrel mechanism. The positioning of this unit at the bottom of the assembly takes advantage of gravity-assisted feeding from the mixer. Its operation flow demonstrates the logical progression from pulverizing to extrusion. The units were mounted on a unified angular steel frame, which provided mechanical stability and minimized vibration. Integration with a Variable Frequency Drive (VFD), seen in allowed fine-tuning of speed and torque across the system, while the inclusion of an operator platform and railings enhanced usability and safety.



(a) (b)  
Figure 4: The two-stage pulverizer. (a) Knife-blade Shredder (b) Hammer Mill.  
Source: Authors, (2026).



Figure 5: Paddle-type Mixer.  
Source: Authors, (2026).



Figure 6: Screw-type Briquetting Assembly.  
Source: Authors, (2026).

### III.2 EFFICIENCY ASSESSMENT

The performance evaluation of the 3-in-1 integrated system revealed high material efficiency across all functional units, validating the design's capacity to minimize losses and maximize conversion from raw biomass to briquette output. Efficiency values were derived from actual mass measurements taken before and after each unit operation. Table 1 presents the individual efficiency for individual unit. As shown in the table, the individual efficiencies for pulverizing unit, mixing unit and briquetting unit are 94.5%, 98.0% and 95.0%, respectively. From (2), the overall system efficiency, OE, was computed as follows:

$$OE = 0.945 \times 0.98 \times 0.95 = 0.8798$$

This result confirms that nearly 88% of the total input material was successfully converted into finished briquettes, with minimal material losses. This level of efficiency surpasses the performance of many conventional, disaggregated systems that typically operate within the 70%–85% range [14], [15]. The high performance can be attributed to the integrated layout, reduced material handling, and continuous process flow between stages.

Table 1: Material Efficiency for Individual Unit.

| Unit (Components)                                | Input Mass, $M_i$ (kg) | Output Mass, $M_o$ (kg) | Material Efficiency, %<br>( $M_o/M_i \times 100$ ) |
|--------------------------------------------------|------------------------|-------------------------|----------------------------------------------------|
| Pulverizer (50% Coco shell & 50% Cacao Pods)     | 7                      | 6.6                     | 94.5                                               |
| Mixer (Coal Dust, Cacao Pods, Binder, and Water) | 10                     | 9.8                     | 98                                                 |
| Briquetter (Complete Mixture from the Mixer)     | 9.8                    | 9.3                     | 95                                                 |

Note: Formulation of the mixture is 70% materials (coco shell & cacao pods), 20% binder & 10% water.

Source: Authors, (2026).

### III.3 THROUGHPUT CAPACITY

The capacity of each unit was measured in kilograms per hour (kg/hr) using the formulas in Section 2.4. The pulverizing capacity (PC), mixing capacity (MC) and briquetting capacity (BC) were found to be 28 kg/hr, 42.8 kg/hr and 27 kg/hr, respectively. As the system is arranged in a sequential flow, the briquetting unit, being the slowest, determined the system's overall capacity, OC, being 27 kg/hr. This bottleneck reflects the intrinsic compression time and extrusion rate of the screw-type briquetting unit. Nonetheless, the system demonstrates sufficient throughput for small-scale applications such as rural fuel cooperatives, local vendors, and decentralized renewable energy initiatives. These results confirm the system's suitability for continuous operation in low-resource environments, especially where commercial-scale machinery is economically infeasible or logistically impractical.

### IV. CONCLUSIONS

This study successfully designed, fabricated, and tested a compact, modular 3-in-1 machine for the efficient conversion of agricultural waste into biomass briquettes. By integrating pulverizing, mixing, and briquetting into a unified structure powered by a single motor, the system streamlines solid fuel production and eliminates the inefficiencies associated with separate machinery. The device achieved an impressive overall efficiency of 87.98% and a throughput capacity of 27 kg/hr, making it well-suited for small-scale and community-level applications. The inclusion of adjustable features, such as the VFD-controlled drive and modular subunits, ensures flexibility, maintainability, and user adaptability. This innovation has the potential to significantly contribute to localized energy resilience, agricultural waste management, and sustainable economic development. Future improvements may include the addition of a briquette cutter, real-time process sensors, or an integrated drying system to enhance fuel quality and production control. Further testing using diverse feedstock compositions would also help generalize applicability across regions and biomass types.

### V. AUTHOR'S CONTRIBUTION

**Conceptualization:** Renante O. Sangel, Consorcio S. Namoco Jr.

**Methodology:** Renante O. Sangel, Consorcio S. Namoco Jr.

**Investigation:** Renante O. Sangel

**Discussion of results:** Renante O. Sangel, Consorcio S. Namoco Jr.

**Writing – Original Draft:** Renante O. Sangel

**Writing – Review and Editing:** Consorcio S. Namoco Jr.

**Resources:** Renante O. Sangel, Consorcio S. Namoco Jr..

**Supervision:** Consorcio S. Namoco Jr.

**Approval of the final text:** Consorcio S. Namoco Jr.

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