A Battery-Powered Solution: Enhancing Rice Paddy Collection Efficiency through Sustainable Technology

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ABSTRACT

This study presents the design, fabrication, and testing of a battery-powered rice paddy grain collector aimed at improving efficiency in the post-harvest phase of rice production. The conventional methods of manual grain collection and gasoline-powered machines are labor-intensive, time-consuming, and environmentally unsustainable. To address these issues, the battery-powered grain collector was developed using locally available materials, with a vacuum suction mechanism for collecting sun-dried rice paddy. The machine operates on a 12V lead-acid battery, reducing reliance on nonrenewable fuel sources and offering a more sustainable solution for rice farmers. The grain collector demonstrated a collecting capacity of 89.67 kg/hr and an efficiency of 81.00%. A cost analysis showed that the machine's operating cost is significantly lower than traditional methods, with a break-even point of 510,606.75 kg/yr. Additionally, the machine proved to be effective in reducing labor requirements, and the total operating time increased with thicker layers of rice paddy. The results indicate that this grain collector offers a practical, cost-effective, and environmentally friendly alternative for small- to medium-scale rice farmers, contributing to the sustainability of rice production.

Keywords: Battery-powered grain collector, Rice paddy collection, Agricultural sustainability, Post-harvest efficiency, Vacuum suction mechanism

INTRODUCTION

Post-harvest operations are vital in rice production, involving processes such as threshing, cleaning, drying, milling, grading, weighing, and storage (Japan International Cooperation Agency, 2015). The efficiency of each stage significantly affects rice quality, milling recovery, loss reduction, and overall market value. These operations can be performed manually or mechanically, with drying being one of the most critical steps due to its influence on milling outcomes, storage stability, and post-harvest losses.

In the Philippines, sun drying is a prevalent method due to its low cost compared to mechanical alternatives. The International Rice Research Institute (2007) describes this method as spreading grains under the sun on surfaces such as mats or roadsides, followed by periodic turning using a wooden board to ensure even drying. Despite its simplicity and affordability, sun drying is highly weather-dependent. Sudden rainfall often forces farmers to hastily collect and protect their grains, a process that is both labor-intensive and time-consuming.

To address these challenges, mechanical solutions have been introduced, including grain collectors that enhance efficiency and reduce manual labor. For example, Santosh M. and Sunilkumara H. (2019) developed a grain collector that significantly improved grain collection speed and reduced labor requirements. However, many existing machines rely on engine-driven systems powered by nonrenewable fuels such as diesel and gasoline, which contribute to environmental degradation. Additionally, the Philippines' reliance on imported fuels from countries like Indonesia, China, Korea, Malaysia, and Singapore (World Integrated Trade Solution, 2020) exposes farmers to volatile fuel prices, further impacting production costs.

Given these concerns, the development of more sustainable technologies has become crucial. This study introduces a battery-powered rice paddy grain collector, designed and fabricated using locally available materials. This machine aims to streamline grain collection, reduce dependence on nonrenewable fuels, and provide farmers with a cost-effective, eco-friendly alternative to traditional methods. Furthermore, the machine's reliance on a lead-acid battery prompts considerations for recycling and environmental impact mitigation, ensuring sustainability throughout its lifecycle.

METHODOLOGY

Conceptual Framework

The growing global population has driven the development of various agricultural machines to meet the rising demand for food. For rice farmers, this often means adopting mechanized processes to increase production efficiency. However, grain collection processes have not yet seen significant advancements; traditional methods are time-consuming and labor-intensive, while existing machines often rely on high fuel consumption. The conceptual framework of this study, shown in the figure below, illustrates the approach taken to address these challenges. A battery-powered rice paddy grain collector was designed and fabricated using locally available materials to assist farmers in collecting rice paddy more efficiently, reducing time, labor, and cost.

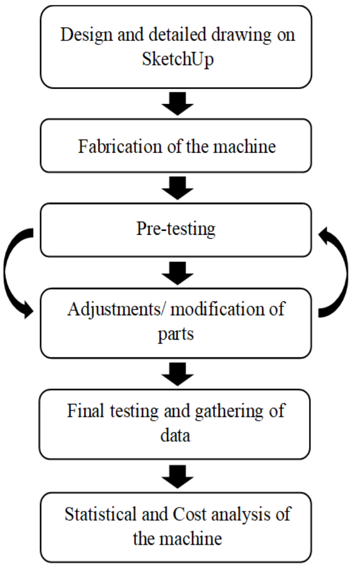

Figure 1. Conceptual Framework

Design Conceptualization

The researchers developed a battery-powered grain-collecting machine based on the principles of vacuum suction. A suction nozzle, connected to a cyclone separator, gathers sun-dried rice paddy from the ground and deposits it into a rice bag. A vacuum motor generates the necessary suction to collect the rice paddy, while four wheels enable smooth movement of the machine.

Figure 1. Isometric view of the design

Filipino farmers typically dry rice grains on concrete roads, occupying part of the roadway to spread the grains. Consequently, the machine's width was designed to align with the traditional width of spread-out rice paddy. Its height was tailored to suit both the average height of Filipino farmers and the height of a standard rice bag. Figure 1 shows an isometric view of the initial design of the battery-powered grain collector.

Collecting Mechanism

The collecting mechanism of the grain collector operates similarly to a vacuum cleaner. Based on Bernoulli's principle, as air speed increases, air pressure decreases. Air flows from high-pressure areas to low-pressure areas, balancing the pressure difference. The grain collector's intake port serves as the suction mouth where air enters, and the exhaust port is where air exits. Inside the machine, a fan forces air toward the exhaust port at high speed, creating low pressure and thus, suction. This high outside pressure pushes air and grains through the suction mouth and into the cyclone separator via the collecting hose.

The cyclone separator traps the paddy and dust mixture due to the outer vortex flow. When the separator is full, air slows down, increasing pressure and reducing suction power, which stops grain intake. Air from the inlet moves up through a middle tube and exits at the separator's overflow outlet, while grains are collected at the bottom, where a bag is positioned for collection.

Field Operational Pattern

A specific operational pattern was applied during the machine's testing and evaluation. The operational width was based on the effective collection range of the suction mouth (7 inches from a 10-inch suction nozzle). A 10% overlap (0.7 inches) was included to optimize collection capacity and efficiency.

Fabrication of the Machine

The machine was designed and fabricated using locally available materials and standard shop tools at JHT Micro Enterprises in Talavera, Nueva Ecija, Philippines and within CLSU. Materials included metal rods, aluminum sheets, welding rods, and fasteners, while tools such as rulers, calipers, pliers, wrenches, and milling machines were used. Fabrication involved cutting, shearing, bending, welding, machining, and assembly. Safety measures were strictly followed to prevent accidents, and the machine's stability was tested under varying load conditions.

Test Parameters

Power Requirement

The power requirement for the machine was determined based on its volumetric flow rate and dynamic pressure. This calculation allowed the researchers to assess the energy needed to operate the machine efficiently.

$$Power\ requirement = Q \times DP \quad \text{Eq. (1)}$$

Where,

$Q = volumetric\ rate, m^3/s$

$DP = Dynamic\ pressure, Pa$

$$Q = vA \quad \text{Eq. (2)}$$

Where,

$v = velocity, m/s$

$A = Area\ of\ inlet\ pipe, m^2$

$$DP = \frac{1}{2}\rho v^2 \quad \text{Eq. (3)}$$

Where,

$\rho = density\ of\ rice\ paddy, 1220\ kg/m^3$

Electric Consumption

The researchers calculated the machine's electric consumption in pesos using the equation provided below. Electric current measurements were obtained using a locally available current meter.

$$E_c(Php) = \frac{Electric\ current \times Voltage\ charger \times T \times Cost\ per\ kWh}{1000} \quad \text{Eq. (4)}$$

Where,

$E_c = Electric\ cost, (Php)$

$T = Charging\ Time$

Collecting Capacity

The collecting capacity of the machine is defined as the total weight of paddy collected over a specified time period. This capacity was calculated using the following method:

$$F_c = \frac{W_{cp}}{T} \quad \text{Eq. (5)}$$

Where,

$F_c = collecting\ capacity, \frac{kg}{h}$

$W_{cp} = weight\ of\ collected\ paddy, kg$

$T = Total\ time\ of\ collection, hr$

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Collecting Efficiency

The collecting efficiency of the machine was calculated by comparing the total weight of paddy collected to the combined weight of collected paddy and collection loss. Collection loss was defined as the weight of rice paddy left uncollected by the machine. The formula used to determine collecting efficiency is as follows:

$$C_e = \frac{W_{cp}}{W_{cp} + C_l} \times 100 \qquad \text{Eq. (6)}$$

Where,

$C_e = collecting\ efficiency$
$W_{cp} = weight\ of\ collected\ paddy, kg$
$C_l = weight\ of\ collection\ loss, kg$

Final Testing Parameters for the Grain Collecting Machine

1. **Energy Required to Run the Machine**

   The energy or power requirement was determined using Equations (1), (2), and (3).

2. **Electric Consumption**

   Electric consumption was calculated by measuring the current flow, battery charger voltage, total charging time, and the cost of electricity per kWh.

3. **Total Operating Time**

   The total operating time was measured using a timer. Three operational times were recorded for each of the three treatments. The timer started when the machine began collecting rice paddy grains. Any time spent on adjustments, turning, or machinery breakdown was subtracted from the total operating time.

4. **Capacity of the Machine**

   The machine's capacity, equivalent to its collecting capacity, was determined by the weight of sun-dried rice paddy (kg) collected over a specific time period.

5. **Machine Efficiency**

   The efficiency of the fabricated machine was calculated using Equation (6).

RESULTS AND DISCUSSION

Description of the Battery-Powered Grain Collector

The grain collector was designed to operate on renewable power sources rather than gasoline, making it more environmentally friendly. Key components of the battery-powered machine include a vacuum motor, a 12VDC to 220VAC power inverter, a Lead Acid battery, a cyclone separator, caster and rubber wheels, a machine frame, a collecting hose, and a suction mouth. By using a Lead Acid battery as the primary power source, this machine minimizes gasoline use in agricultural machinery.

The design aims to reduce the need for manual labor in grain collection from sun-drying systems and lower gasoline consumption in agricultural production, supporting energy conservation efforts. Figure 3 shows the actual battery-powered grain collector, and Table 1 provides the machine's specifications.

Figure 3. Battery powered grain collector

Table 1. Specifications of the Battery-Powered Grain Collector

Specification	Value
Height	3.70 ft
Length	2.20 ft
Width	2.92 ft
Weight	15 kg (without load)
Noise Level	95 dB
Dynamic Air Pressure	115 Pa
Air Velocity	9-13 m/s
Collecting Capacity	89.67 kg/hr
Collecting Efficiency	81.00%
Unit Cost	Php 7,843
Vacuum Motor	800 Watts AC motor
Lead Acid Battery	12V, 38 Amperes Hour
Power Inverter	10,000 Watts peak power (5,000 Watts rated)
Cyclone Separator	Height: 22.5 inches
	Inlet opening diameter: 2 inches
	Outlet opening diameter: 4 inches
Caster Wheel	4 inches diameter (1 inch thick)
Rubber Wheel	10 inches diameter (2 inches thick)
Machine Frame	Height: 39 inches, Width: 27 inches, Length: 26 inches
Collecting Hose	Diameter: 2 inches
Suction Mouth	Width: 10 inches, Length: 3.5 inches

The battery-powered grain collector designed for this study is a significant advancement over traditional, gasoline-powered grain collection methods. By utilizing a 12V Lead Acid battery as the primary power source, this machine addresses the growing concern over fuel consumption and environmental impact in agricultural machinery.

The machine’s design focuses on efficiency and practicality, with a compact and robust frame. With a

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height of 3.70 ft, length of 2.20 ft, and width of 2.92 ft, the machine is both portable and suitable for maneuvering in the fields. Weighing 15 kg without load, it offers a balance of sturdiness and ease of operation, while its noise level of 95 dB is comparable to that of conventional agricultural equipment.

The dynamic air pressure of 115 Pa and air velocity of 9-13 m/s indicate that the machine's vacuum system is capable of creating sufficient suction power to collect rice paddy effectively. This is further supported by its collecting capacity of 89.67 kg/hr, demonstrating the machine's ability to handle a significant volume of grain within a short period.

The collecting efficiency of 81.0% indicates a high level of performance, though there remains room for optimization in minimizing collection loss. This efficiency level is consistent with the aim to reduce manual labor and improve the speed and quality of grain collection compared to traditional methods.

The vacuum motor, rated at 800 Watts, and the power inverter with a peak power of 10,000 Watts ensure that the machine operates efficiently with adequate energy reserves. The combination of these components enables the machine to function effectively in the field while maintaining the convenience of battery-powered operation. The specified 12V, 38 Ampere Lead Acid battery offers a reliable power source for sustained use.

The machine's overall cost, Php 7,843, makes it an affordable alternative to more expensive, gasoline-driven grain collectors. Additionally, its components, such as the cyclone separator and the collecting hose with a 2-inch diameter, contribute to its ability to collect rice paddy with minimal disruption to the grains, reducing waste and improving efficiency.

In terms of mobility, the 4-inch diameter caster wheels and 10-inch rubber wheels provide stable support and maneuverability on varied terrain, enhancing the practicality of the grain collector in real-world agricultural settings.

Overall, the battery-powered grain collector demonstrates an effective balance of efficiency, cost, and environmental sustainability. However, further improvements in the suction system or other mechanical components may increase its performance and energy efficiency, thereby further reducing collection losses and operational time.

Operating Characteristics of the Machine

Power Requirement

The grain collector operates using an 800 W vacuum motor with a suction mechanism capable of achieving 22 CFM, which produces a maximum air velocity of 13.3 m/s and a maximum dynamic air pressure of 114 Pa. The machine's collecting capacity is 122.84 kg/hr.

To determine the power requirement, the researchers used the 22 CFM (equivalent to 0.0104 m^3/s) and divided it by the area of the inlet pipe using Equation (1). This resulted in a velocity of 10.83 m/s. The calculated velocity was then used to determine the actual dynamic pressure required to collect the rice paddy, using Equation (3), yielding a dynamic pressure of 71,546.30 Pa. The power requirement was then calculated by multiplying the dynamic pressure with the volumetric flow rate, resulting in a total power requirement of 744.08 Watts.

Electric Consumption

The electric consumption of the grain collector was determined using Equation (4). The electric current, voltage of the charger, charging time, and the current price of electricity in Nueva Ecija were taken into

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account.

According to the Nueva Ecija Electric Corporation Inc. (NEECO), the current price of electricity is Php 9.35 per kWh. With the current meter reading of 0.4 Ah and a charging time of 3 hours for one battery, the electric consumption of the machine during 11 minutes of operation (the total operating time for one battery) was calculated to be Php 2.58.

Total Operating Time

The total operating time of the grain collector was determined through three different treatments:

- **T1 (0.5–1 cm)**
- **T2 (1–1.5 cm)**
- **T3 (1.5–2 cm)**

Each treatment used 25 kg of rice paddy. Table 2 shows the total operating time for each treatment. For Treatment 1 (0.5–1 cm), the grain collector took 12.33 minutes to collect the rice paddy. In Treatment 2 (1–1.5 cm), the collection time increased to 13.96 minutes. For Treatment 3 (1.5–2 cm), the machine took 15.32 minutes to collect the rice paddy. These results demonstrate that the total operating time increases as the thickness of the spread-out rice paddy increases.

Collecting Capacity

The collecting capacity was determined by dividing the actual amount of rice paddy collected by the collection time, and the result was expressed in kg/hr. Table 3 shows the descriptive statistics of the collecting capacity, with a minimum value of 63.92 kg/hr, a maximum value of 115.22 kg/hr, a mean of 89.67 kg/hr, and a standard deviation of 19.83.

The analysis of variance (ANOVA) showed that, at the 95% level of significance, there was a significant difference in the collecting capacity of the battery-powered grain collector when subjected to different grain thicknesses (0.5–1.0 cm, 1.0–1.5 cm, and 1.5–2.0 cm). Using the Least Significant Difference (LSD) test, the comparison of treatment means, presented in Table 4, revealed that Treatment 1 (0.5–1.0 cm), with the thinnest grain thickness, achieved the highest collecting capacity at 111.78 kg/hr. This was followed by Treatment 2 (1.0–1.5 cm) at 90.52 kg/hr, and Treatment 3 (1.5–2.0 cm) at 66.72 kg/hr. This result implies that to attain higher collecting capacity, thinner grain thicknesses during collection should be prioritized.

Machine Efficiency

The collecting efficiency was calculated by dividing the actual amount of rice paddy collected by the total amount of grains. Table ** shows the descriptive statistics of the collecting efficiency, with a minimum value of 65.20%, a maximum value of 92.48%, a mean of 81.00%, and a standard deviation of 10.28.

The ANOVA at the 95% level of significance indicated a significant difference in the collecting efficiency of the battery-powered grain collector when subjected to different grain thicknesses (0.5–1.0 cm, 1.0–1.5 cm, and 1.5–2.0 cm). Using the LSD test, the comparison of treatment means presented in Table ** showed that Treatment 1 (0.5–1.0 cm) had the highest efficiency at 90.77%, followed by Treatment 2 (1.0–1.5 cm) at 84.13%, and Treatment 3 (1.5–2.0 cm) with the lowest efficiency at 68.11%. This result justifies that as the thickness of the rice paddy increases, the efficiency of the machine decreases.

Economical Analysis

A simple cost analysis was performed after the final testing of the machine to determine its economic efficiency. The machine is assumed to be used for 120 hours annually, with 2 hours of operation per day and one operator responsible for both operating the machine and bagging the rice paddy.

The total cost of the machine was Php 12,501.76. The fixed cost for collecting rice paddy using the machine annually was Php 2,021.93, while the variable cost was Php 10,479.83. The cost of collecting paddy using the battery-powered grain collector was Php 0.07 per kg (or Php 3.50 per cavan), while the prevailing custom rate for collecting paddy was Php 0.11 per kg (or Php 5.50 per cavan), which is 45.83% of the cost of sun drying.

The break-even point for the machine was determined to be 510,606.75 kg per year (or Php 56,166.74). Utilizing the machine for 120 hours annually would generate an income of Php 5,016.17. The projected time to recover the cost of the machine, based on its collecting capacity of 111.78 kg/hr and the custom rate of Php 0.11 per kg, was 3.65 years.

CONCLUSION

The battery-powered grain collector designed and fabricated in this study proved to be a promising alternative to traditional methods of rice paddy collection. The machine demonstrated a significant reduction in labor and time, offering an efficient solution to the manual and fuel-intensive processes currently employed by Filipino farmers. With a collecting capacity of 89.67 kg/hr and an efficiency of 81.00%, the machine successfully met the objectives of minimizing fuel usage and enhancing labor productivity. Additionally, the analysis confirmed that thinner rice grain thicknesses (0.5–1.0 cm) yielded higher collecting capacity and efficiency. The economic analysis further highlighted the feasibility of the machine, with a projected payback period of 3.65 years based on its collecting capacity and operating costs.

This grain collector, powered by a lead-acid battery, significantly contributes to sustainable agricultural practices by reducing dependency on nonrenewable fuel sources and providing a cost-effective alternative to traditional grain collection methods.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. **Optimization of Grain Thickness:** To maximize the collecting capacity and efficiency, it is recommended that farmers spread the rice paddy to a thickness of 0.5–1.0 cm during sun drying. This will allow the grain collector to operate at its highest capacity.
2. **Further Improvements in Battery Life:** Although the machine demonstrated efficient performance, future research should focus on enhancing the battery life and performance. This can potentially reduce charging time and improve the machine’s operating efficiency over longer periods.
3. **Development of Larger Scale Machines:** To cater to larger farms, the design could be scaled up to increase its collecting capacity. This will make the machine suitable for commercial rice farmers who have larger areas to cover during harvest.
4. **Long-term Field Testing:** It is recommended that the machine undergoes long-term testing in diverse field conditions to assess its durability, maintenance needs, and performance in various environmental settings.
5. **Substitution of Battery with More Sustainable Options:** Exploring more sustainable battery technologies, such as lithium-ion or solar-powered options, could further reduce environmental impact and improve the cost-effectiveness of the grain collector in the long term.
6. **Training for Farmers:** To ensure the machine’s optimal usage, training programs for farmers on machine operation, maintenance, and safety should be implemented.

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