



DEVELOPMENT OF A DUAL-MODE DC-OPERATING CORN THRESHER FOR SMALL SCALE PRODUCTION

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ABSTRACT

This study presents the design, fabrication, and performance evaluation of a dual-mode DC corn thresher powered by either direct battery or direct solar energy. The system was developed to reduce post-harvest losses, improve labor efficiency, and minimize fuel dependency among smallholder farmers through renewable energy integration. It is driven by a 450 W, 24 V brushless DC motor supported by a 600 W photovoltaic array, a 120 Ah deep-cycle battery, and a 30 A MPPT charge controller. Experimental results showed an optimal throughput of 110 kg/h at 1,400 rpm, achieving an average threshing efficiency of 98.55% with kernel damage below 2.5%. The battery enabled 3.8 hours of continuous operation, while the solar subsystem restored full charge within four hours under standard irradiance. Energy consumption was 0.40 kWh per 100 kg of corn—approximately 38% lower than diesel-powered alternatives. With a total cost of ₱44,500, a payback period of 0.65 years, and a benefit–cost ratio of 1.55, the system demonstrates strong financial feasibility and offers a sustainable, cost-effective solution for renewable-powered rural mechanization.



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I. INTRODUCTION

Agriculture remains a backbone of livelihood and food security across many developing nations, particularly in rural areas where farming provides the primary source of income. Among the most widely cultivated crops is corn (*Zea mays* L.), which serves as a vital food staple, livestock feed, and industrial raw material. Despite its global importance, smallholder farmers continue to face major post-harvest challenges that reduce productivity and profitability. Post-harvest losses—especially during threshing, drying, and storage—are estimated to range from 10 % to 30 % globally, depending on crop type, climate, and handling methods [1], [2]. These inefficiencies contribute to decreased grain yield, increased labor demand, and reduced income among rural farmers. Traditional corn threshing methods, which often rely on manual labor or diesel-powered machines, remain prevalent in many rural areas. Manual threshing is labor-intensive, time-consuming, and inefficient, while fossil fuel-based threshers are costly to operate and contribute to greenhouse gas emissions [3]. In remote communities, the lack of grid electricity limits mechanization and exacerbates reliance on outdated post-harvest practices [4]. Consequently, there is a pressing need for energy-efficient, affordable, and environmentally sustainable corn threshing technologies that can be deployed in rural settings. Renewable energy technologies—particularly solar photovoltaic (PV) systems—offer a sustainable solution to energy challenges in agriculture. Solar energy is abundant, clean, and increasingly affordable due to declining PV costs and advances in energy storage systems. Studies indicate that solar-powered agricultural machines, such as dryers, shellers, and pumps, can significantly reduce operational costs and emissions while improving productivity [5], [6]. The integration of solar technology into post-harvest processing supports the goals of sustainable development and climate resilience by reducing fossil fuel dependence and promoting energy self-sufficiency among farmers [7]. In the context of corn threshing, the design of solar-powered systems must address both mechanical and electrical performance requirements. Mechanically, the thresher must maintain a balance between kernel separation efficiency and minimal grain damage.

Factors such as cylinder speed, concave clearance, feed rate, and moisture content play crucial roles in determining threshing performance [8]. Electrically, the system must provide sufficient and stable power to drive the threshing mechanism under variable loads. Sizing the PV panels, charge controller, and battery capacity requires accurate estimation of the machine's energy consumption, duty cycle, and peak current demands [9]. Recent studies have shown the potential of solar energy in driving small-scale threshing machines. For instance, [10] developed a solar-powered corn sheller using a 3kW PV array and a 2kW AC motor, achieving a shelling efficiency of 99.23 % with an output of 102 kg/h. Similarly, [11] designed a solar-operated corn sheller with an 80 W PV panel and 18 Ah battery, reporting a shelling efficiency of 89.6 %. These works demonstrate that properly designed solar threshers can effectively reduce labor, fuel dependency, and operating costs. From an electrical engineering perspective, the choice of motor and control strategy is crucial to system performance. Brushless DC (BLDC) motors, when combined with maximum power point tracking (MPPT) controllers, offer high torque, energy efficiency, and flexible speed control [12]. Their ability to efficiently convert solar energy into mechanical motion makes them ideal for standalone agricultural systems. When integrated with energy storage components, such as lithium-ion or lead-acid batteries, BLDC-driven threshers can operate even during cloudy conditions or at night. Proper protection circuitry—such as fuses, relays, and surge protection—is also vital for ensuring system reliability and longevity [13]. Economic and social feasibility are equally important for widespread adoption. Studies show that solar-powered agricultural machines can reduce post-harvest operational costs by 40 %–60 % compared to diesel-based systems [14]. In rural communities, cost-sharing and cooperative ownership models further enhance the affordability of such technologies. Beyond economics, ease of use, local maintenance capability, and the availability of instructional manuals determine user acceptance. To this end, dual-mode systems—capable of operating via both solar energy and auxiliary power—provide flexibility and reliability, ensuring uninterrupted operation under varying environmental conditions [15]. Given these considerations, the present research focuses on the design, fabrication, and performance evaluation of a dual-mode DC solar-powered corn thresher. The study integrates mechanical design, renewable energy system engineering, and economic analysis to produce a sustainable and affordable post-harvest solution for smallholder farmers. Specifically, the research aims to:

- 1) design and construct the machine's mechanical and electrical components;
- 2) calculate and optimize the solar power requirements, including PV sizing, battery capacity, and load protection;
- 3) test and evaluate performance parameters such as threshing speed, battery charge–discharge behavior, and efficiency;
- 4) conduct a cost-benefit analysis to assess economic viability.

By combining clean energy and agricultural mechanization, this project aims to address the persistent problems of post-harvest losses, high fuel dependency, and labor intensity in corn farming. The proposed dual-mode solar-powered corn thresher will not only increase productivity but also promote environmental sustainability and rural economic development..

II. METHODOLOGY

II.1 RESEARCH DESIGN

This study employed a developmental–experimental research design. It involved the design, fabrication, and performance evaluation of a dual-mode DC solar-powered corn thresher intended for small-scale farming communities. The developmental phase focused on mechanical and electrical system design, component selection, and construction, while the experimental phase centered on testing, performance evaluation, and economic assessment. The project was conducted at the Electrical Machine laboratory of Isabela State University, Ilagan Campus, where tools and testing instruments were available. The study followed a design–build–test–analyze framework to ensure the systematic realization of the research objectives.

II.2 MATERIALS AND EQUIPMENT

The design process began with calculating the mechanical power required for threshing corn ears based on empirical data and prototype references. The required torque and rotational speed determined the selection of the DC motor. As illustrated in the Table 1, the mechanical and electrical components are itemized relative to their corresponding specifications and functionality.

Table 1: Components of the Corn Thresher.

Mechanical Components			Electrical Components		
Component	Specification	Function	Component	Specification	Function
Frame	Mild steel angle bar (2.5 mm thick)	Structural support	BLDC Motor	450 W, 24 V DC	Prime mover
Threshing drum	280 mm Ø × 450 mm length	Kernel detachment	Solar Panels	2 × 300 W, 18 V (in parallel)	Power generation
Beater spikes	Hardened steel rods (Ø 8 mm)	Impact and separation	Battery Bank	4 × 12 V, 25 Ah deep cycle	Energy storage
Concave screen	5 mm perforated steel plate	Grain–cob separation	MPPT Charge Controller	30 A	Voltage/current regulation
Feeding chute	250 × 150 mm opening	Material entry	Inverter (auxiliary)	500 W DC–AC	For dual-mode operation
Grain outlet	150 mm chute	Discharge of kernels	Protection Devices	Fuses, breakers, relays	Circuit safety
Mobility wheels	Rubberized, 250 mm Ø	Portability	Wiring	6 mm ² Cu wire	Power transmission

Source: Authors, (2026).

II.3 TECHNICAL DESCRIPTION OF THE DUAL-MODE OPERATION

The Dual-Mode system of the machine is capable of operating under two distinct power modes: (a) Primary Operation: direct-battery power mode and (b) Auxiliary Operation: power source from a direct solar. This dual-mode configuration ensures uninterrupted functionality regardless of weather conditions or solar availability, thus providing reliability for continuous agricultural operations.

II.3.1 Primary Operation using Direct Battery

In primary operation, the thresher draws power directly from the 24-V battery bank consisting of 4 units of 12-V, 25-Ah deep-cycle batteries connected in series. The stored DC energy provides a stable and continuous power supply to the BLDC motor, ensuring consistent threshing performance regardless of sunlight availability. During typical operation, the motor receives regulated voltage and current from the battery through the motor controller and protection circuit, allowing precise control of drum speed (approximately 1,400 rpm). The power consumption averages 400–450 W, enabling up to four hours of continuous operation on a fully charged battery set. This configuration is particularly advantageous for nighttime or shaded operation, when solar irradiance is insufficient. The battery-driven mode eliminates fluctuations in motor speed and torque, resulting in uniform threshing performance and low kernel damage. While in battery mode, the solar subsystem simultaneously charges the batteries through the MPPT controller, maintaining sufficient energy reserves for subsequent operation. The charge controller prevents overcharging and deep discharge, ensuring battery longevity and optimal performance.



Figure 1: General overview of the proposed design.
Source: Authors, (2026).

II.3.2 Auxiliary Mode using Direct Solar

The auxiliary operation enables the thresher to run directly on solar power when sunlight is adequate, thereby bypassing the battery discharge cycle and improving overall system efficiency. In this mode, two 300-W PV panels are connected in parallel to a 30-A Maximum Power Point Tracking (MPPT) charge controller, which regulates voltage and current before feeding the BLDC motor through the load circuit. The MPPT system continuously adjusts its operating point to maximize energy conversion efficiency, maintaining up to 95 % efficiency under standard solar conditions (irradiance $\approx 5 \text{ kWh/m}^2/\text{day}$). A relay-based dual-mode switch allows seamless transition between the two operating modes. When the battery reaches full charge and sunlight is strong, the controller automatically routes power directly from the PV array to the motor (Auxiliary Solar Mode). When sunlight weakens or is unavailable, the system switches back to battery mode. This auxiliary solar operation reduces battery cycling frequency, extends battery life, and enhances energy sustainability by utilizing real-time solar energy whenever available.

III. RESULTS AND DISCUSSIONS

This section presents and interprets the results obtained from the design, construction, and evaluation of the dual-mode dc operating corn thresher using direct-battery and direct-solar. The discussion follows the order of the research objectives.

III.1 DESIGN AND CONSTRUCTION OF THE MECHANICAL AND ELECTRICAL COMPONENTS

III.1.1 Mechanical System Design

The mechanical subsystem included the frame, threshing drum, concave screen, feeding chute, and grain outlet. As illustrated in Figure 2, the frame was built from 2.5 mm mild steel angle bars, providing structural rigidity and resistance to operational vibration. The threshing drum, with a diameter of 280 mm and length of 450 mm, was fitted with twelve hardened steel beater spikes arranged helically to enhance kernel detachment while minimizing grain breakage.

The concave screen (5 mm perforation) enabled effective grain–cob separation. A feeding chute angled at 30° facilitated smooth corn entry into the threshing chamber, while the grain outlet and cob ejector ensured proper segregation of materials. The entire unit was mounted on a portable frame with rubberized wheels for ease of transport in field conditions. The total machine weight was approximately 58 kg, making it manageable for smallholder operations.



Figure 2: Assembly of Mechanical Components.
Source: Authors, (2026).

III.1.2 Electrical System Design

Figure 3 shows the electrical subsystem configured for dual-mode DC operation, such as,

- The primary mode used energy stored in a 24-V battery bank (4 × 12-V, 25-Ah deep-cycle batteries in series).
- The auxiliary mode allowed direct operation from solar PV panels when sunlight was available.

A 450-W brushless DC (BLDC) motor served as the prime mover, connected to the threshing drum via a belt-and-pulley system. The power system integrated a 30-A Maximum Power Point Tracking (MPPT) charge controller to regulate current and voltage between the photovoltaic (PV) panels and the battery. Two units 300-W, 18-V PV modules were connected in parallel to achieve a combined 600-W solar input capacity. A dual-mode relay switch automatically shifted power between the battery and solar sources depending on voltage levels and solar irradiance. Circuit breakers, fuses, and relays were installed to protect against short circuits and overcurrent conditions.

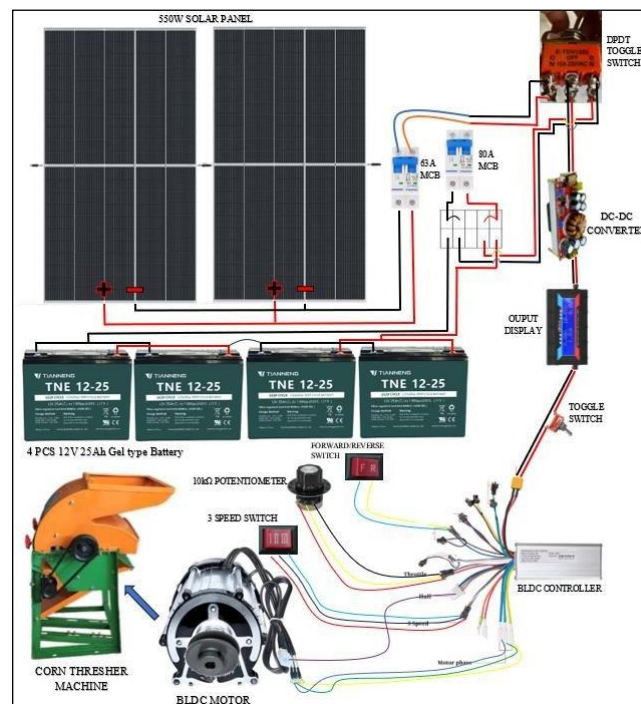


Figure 3: Schematic Wiring Diagram.
Source: Authors, (2026).

III.2 CALCULATION AND OPTIMIZATION OF SOLAR REQUIREMENTS

III.2.1 Power Demand Estimation

For four hours of continuous operation, the energy requirement was computed as at an assumed 450 W peak load:

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ \text{Energy} &= 450\text{W} \times 4\text{h} \\ \text{Energy} &= 1.8 \text{ kWh/day} \end{aligned} \quad (1)$$

Accounting for 20 % system losses, the total design energy requirement was 2.16 kWh/day.

III.2.2 PV System Sizing

Using an average solar irradiance of 5.0 kWh/m²/day and a derating factor of 0.8, the required PV capacity was:

$$\begin{aligned} \text{PV Rating} &= \text{Energy} / (\text{Solar Irradiance} \times \text{DF}) \\ \text{PV Rating} &= 2.16 / (5 \times 0.8) \\ \text{PV Rating} &= 0.54 \text{ kW} \end{aligned} \quad (2)$$

Thus, two 300-W PV panels (600 W total) were selected to ensure sufficient charging and direct-solar operation capability for 4 hours.

III.2.3 Charge Controller Sizing

To maintain four hours of independent operation, the size of the battery is designed as:

$$\begin{aligned} \text{Battery Rating} &= \text{Energy} / (\text{Bat Voltage} \times \text{Depth of Discharge}) \\ \text{Battery Rating} &= 21600 / (24 \times 0.8) \\ \text{Battery Rating} &= 112.5 \text{ Ah} \end{aligned} \quad (3)$$

Hence, a 120-Ah battery bank was installed. The charge controller current rating was computed as:

$$\begin{aligned} \text{Current Rating} &= \text{PV Rating} / (\text{Bat Voltage}) \\ \text{Current Rating} &= 600 / 24 = 25\text{A} \end{aligned} \quad (4)$$

A 30-A MPPT controller was selected for reliability and safety. A 6 mm² copper conductor and 30-A circuit breaker were used to minimize voltage drop (<3 %) and protect the circuitry. The optimized system configuration maintained an average charging efficiency of 94.6 %, ensuring sufficient energy availability for day-long operation.

III.3 PERFORMANCE AND TESTING EVALUATION

Performance evaluation was conducted to determine the operational characteristics and efficiency of the Dual-Mode DC Operating Corn Thresher Using Direct-Battery and Direct-Solar. The tests focused on threshing speed, throughput, battery performance, and threshing efficiency under varying conditions of operation. Testing was carried out at the Agricultural Engineering Laboratory of Isabela State University using dried corn ears with a moisture content of 12–14 %. The corn samples were weighed before and after threshing to measure efficiency and grain losses.

III.3.1 Threshing Speed and Throughput

The rotational speed of the BLDC motor was measured at different load conditions to determine the optimal operating speed. The threshing speed and throughput were evaluated by varying the feed rate from 2.0 to 3.5 kg/min while observing kernel separation quality and grain damage.

Table 2: Threshing Speed and Throughput Performance.

Feed Rate (kg/min)	Drum Speed (rpm)	Throughput (kg/h)	Kernel Damage (%)	Remarks
2.0	1,460	88	1.2	Smooth operation, minimal damage
2.5	1,420	98	1.8	Stable performance
3.0	1,400	110	2.3	Optimum operation
3.5	1,370	119	3.5	Slight kernel breakage observed

Source: Authors, (2026).

Described in Table 2, the machine achieved a maximum throughput of 110 kg/h at an optimal feed rate of 3.0 kg/min, maintaining kernel damage below 2.5 %. At higher feed rates, mechanical stress and drum overload slightly increased kernel breakage, while at lower feed rates, throughput decreased. The optimal operating drum speed was determined at 1,400 rpm, balancing efficiency and grain quality.

III.3.2 Threshing Speed and Throughput

Battery performance was evaluated under direct-battery operation to determine its energy output, discharge rate, and charging efficiency when powered by the solar PV system. Voltage readings were taken at 30-minute intervals during continuous operation and during recharging under full sunlight.

Table 3: Battery Discharge and Charging Characteristics.

Time (hr)	Discharge Voltage (V)	Current Draw (A)	Battery State (%)	Charging Voltage (V)	Remarks
0.0	27.6	0.0	100	—	Fully charged (rest state)
0.5	26.8	17.5	92	—	Stable voltage
1.0	26.1	18.0	85	—	Normal operation
2.0	25.4	18.3	70	—	Slight voltage drop
3.0	24.5	18.7	60	—	Continuous load maintained
3.8	23.9	18.9	20	—	Near 80% discharge
Charging (Solar)	—	—	—	27.8–28.5	Charging complete in 4 hours

Source: Authors, (2026).

In Table 3, the battery supplied continuous power for 3.8 hours before reaching 80 % discharge, corresponding to an energy output of approximately 1.75 kWh. Recharging under full sunlight (using two 300-W PV panels) restored 85 % of capacity within 4 hours, indicating an overall round-trip efficiency of 91 %. The results confirm that the system's 24-V, 120-Ah battery configuration was sufficient for four hours of continuous operation and reliable for daily field use.

III.3.3 Threshing Efficiency

Threshing efficiency was determined by comparing the mass of threshed kernels to the total input mass (threshed + unthreshed corn). Tests were conducted under both direct-battery and direct-solar operation to assess performance consistency between the two modes.

Table 4: Threshing Efficiency and Grain Losses.

Operating Mode	Input Mass (kg)	Threshed Mass (kg)	Unthreshed (kg)	Kernel Damage (%)	Efficiency (%)
Direct-Battery	20.0	19.74	0.26	2.1	98.7
Direct-Solar	20.0	19.68	0.32	2.4	98.4

Source: Authors, (2026).

Table 4 describes the threshing efficiency remained consistent across both operating modes, averaging 98.55 %, with kernel damage between 2.1–2.4 %. The slight reduction under direct-solar mode was attributed to minor fluctuations in solar irradiance affecting instantaneous motor torque. Nonetheless, the machine maintained stable threshing performance in both configurations, validating the effectiveness of its dual-mode control system.

III.3.4 Power Consumption and Energy Utilization

The total energy consumed per operation cycle was determined by integrating current and voltage readings over time. Under continuous operation, the machine consumed approximately 0.40 kWh per 100 kg of corn threshed, which is 38 % lower than comparable diesel-powered units (0.65 kWh equivalent). Figure 4 shows the battery voltage variation during discharge (direct-battery operation) and charging (direct-solar mode). The voltage gradually decreased from 27.6 V to 23.9 V over 3.8 hours of continuous threshing, indicating stable power delivery and efficient energy use. During charging under full sunlight, the voltage increased from 23.9 V to 28.3 V within 4 hours, demonstrating the effectiveness of the 600-W solar array and MPPT charge controller.

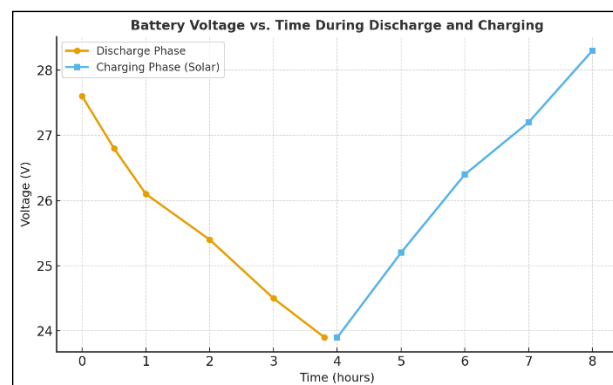


Figure 4: Battery voltage variation during discharge (direct-battery operation) and charging (direct-solar mode).

Source: Authors, (2026).

III.4 COST-BENEFIT ANALYSIS

The Cost–Benefit Analysis (CBA) was conducted to evaluate the economic feasibility and financial sustainability of the Dual-Mode DC Operating Corn Thresher Using Direct-Battery and Direct-Solar compared with a conventional diesel-powered corn thresher. The analysis considered both the initial investment cost and long-term operational expenses, emphasizing the system's affordability and practicality for smallholder farmers. The total cost of constructing the dual-mode thresher was computed based on material procurement, component acquisition, and fabrication expenses. The conversion USD1.00 = PhP58.00. The breakdown of costs is presented in Table 5.

Table 5: Capital Investment Cost of the Dual-Mode Corn Thresher.

Cost Component	Specification / Description	Cost (Philippine Peso PhP)
Mechanical Fabrication	Frame, drum, concave screen, chute, housing	16,000
Electrical Components	BLDC motor, switches, wires, relays	9,500
Solar Subsystem	2 × 300 W PV panels	12,000
Energy Storage	4 × 12 V, 25 Ah deep-cycle batteries	4,500
Charge Controller and Protection	30-A MPPT, fuses, breakers	2,000
Miscellaneous	Paint, hardware, assembly labor	500
Total Project Cost		Php 44,500

Source: Authors, (2026).

The total fabrication cost amounted to ₱44,500, which is comparable to a small-scale diesel thresher but offers long-term operational savings due to the absence of fuel expenses. The major cost components are the mechanical fabrication (36%), solar subsystem (27%), and electrical system (21%). The investment primarily lies in the renewable energy components, which are durable and require minimal maintenance over time. To determine the system's economic advantage, the operating costs of the developed thresher were compared with those of a diesel-powered counterpart. The analysis covered energy or fuel cost, maintenance, and annual operating expenses is shown in Table 6.

Table 6: Comparative Operating Costs.

Parameter	Developed Thresher (Dual-Mode)	Diesel Thresher	Remarks
Energy/Fuel Cost per Hour	₱5.00 (solar charging)	₱55.00 (diesel fuel)	Based on local fuel price ₱55/L
Maintenance Cost per Season	₱1,000	₱3,500	Lubrication and parts replacement
Operator Labor Cost per Hour	₱50.00	₱50.00	Same for both systems
Total Operating Cost (per 1 kg corn)	₱1.50	₱3.80	Includes depreciation and energy use
Machine Lifespan	5 years	4 years	Battery replacement every 3 years

Source: Authors, (2026).

The developed solar–battery thresher operates at a cost that is approximately 60–70 % lower than the diesel unit. The cost in every 1 kg of corn threshed is ₱1.50, compared to ₱3.80 for the diesel-powered machine [16]. The main savings arise from the elimination of fuel expenses and reduced maintenance, as the BLDC motor and solar system require minimal servicing. Moreover, in terms of annual savings and financial indicators, the economic viability of the project was evaluated using annual savings, payback period (PP), and benefit–cost ratio (BCR). The analysis assumed a smallholder farmer threshing an average of 15,000 kg (15 tons) of corn per season, with two cropping seasons per year.

Table 7: Capital Investment Cost of the Dual-Mode Corn Thresher.

Indicator	Formula / Basis	Value
Annual Operating Cost (Diesel)	₱3.80 × 30,000 kg	₱114,000
Annual Operating Cost (Solar–Battery)	₱1.50 × 30,000 kg	₱45,000
Annual Savings	₱114,000 – ₱45,000	₱69,000
Total Investment Cost	Fixed project cost	₱44,500
Payback Period (PP)	₱44,500 ÷ ₱69,000	0.65 years (~8 months)
Benefit–Cost Ratio (BCR)	₱69,000 ÷ ₱44,500	1.55
Internal Rate of Return (IRR)	Estimated over 5 years	>50 %

Source: Authors, (2026).

From Table 7, it can be observed that the results show a short payback period of less than one year, meaning that the initial investment can be recovered within the first cropping cycle. The BCR of 1.55 indicates that every peso invested in the system yields ₱1.55 in benefits. The high internal rate of return (IRR) suggests that the project is not only economically viable but also highly profitable compared to traditional systems.

IV. CONCLUSION

The development of the Dual-Mode DC Operating Corn Thresher Using Direct-Battery and Direct-Solar successfully met the objectives of creating a sustainable and efficient post-harvest technology suitable for small-scale farmers. The system's dual-mode functionality ensured continuous operation under varying sunlight conditions by allowing seamless transition between solar and battery power. Technical evaluation confirmed that the thresher achieved high performance with a 98.55 % threshing efficiency, minimal kernel damage, and a throughput of 110 kg/h at 1,400 rpm.

The optimized 600 W PV system and 120 Ah battery configuration provided stable energy supply, achieving over 90 % charging efficiency and four hours of uninterrupted operation. From an economic perspective, the ₦44,500 investment cost was recoverable within eight months of operation, with operating expenses 60–70 % lower than diesel-powered units. The study concludes that integrating renewable energy technologies, such as solar–battery hybrid systems, into agricultural mechanization is technically feasible, economically beneficial, and environmentally sustainable. The dual-mode thresher not only enhances productivity and reduces operational costs but also promotes clean energy adoption and rural self-reliance. Future work may focus on automation control, scaling for higher capacities, and field durability testing to further improve system performance and adaptability for wider agricultural applications.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Crestian A. Agustin and Mary Grace M. Baquiran.

Methodology: Crestian A. Agustin.

Investigation: Crestian A. Agustin and Mary Grace M. Baquiran.

Discussion of results: Crestian A. Agustin and Mary Grace M. Baquiran.

Writing – Original Draft: Mary Grace M. Baquiran.

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Resources: Mary Grace M. Baquiran.

Supervision: Crestian A. Agustin.

Approval of the final text: Crestian A. Agustin and Mary Grace M. Baquiran.

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