Mechanical Extraction of Pili Pulp Oil: System Development, Yield Performance, and Oil Quality Analysis

Engineer Susan Guevarra; Dr. Lolita G. Musa; Dr. Frederic B. Alinas

University of Makati, Philippines

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ABSTRACT

Pili (*Canarium ovatum*) is a tropical nut crop valued for its oil-rich pulp with applications in food, cosmetic, and pharmaceutical industries. Traditional extraction methods are labor-intensive and produce inconsistent oil quality. This study developed and evaluated a novel electrically driven mechanical extraction system specifically designed for pili pulp, incorporating optimized screw geometry and an integrated post-processing workflow. The prototype features a low-shear screw conveyor, food-grade contact materials, and inline filtration, distillation, decolorization, heating, and cooling modules. Optimal performance was achieved at 20 kg batch size, 20 rpm operating speed, and 20 minutes extraction time, producing 7.1 liters of oil (58.36% yield). Oil analysis showed desirable physical properties (specific gravity 0.89), chemical stability (peroxide value 5.4 meq/kg), and high carotenoid content (56.8 mg/100 g). Compared with manual and village-level presses (Table 5), the prototype improved yield by 4–5× and reduced extraction time by up to 75%. Economic analysis showed a 96% rate of return and 2.4-month payback period. Sensitivity analysis confirmed profitability under varying price, labor, and throughput conditions. The developed system provides a scalable and economically robust solution for standardized pili pulp oil production.

Keywords: Pili pulp oil, mechanical extraction, oil yield, post-processing, screw conveyor, food and cosmetic applications

INTRODUCTION

Pili (Canarium ovatum), a tropical nut tree native to the Philippines, is highly valued for its oil-rich pulp and kernel, which possess significant nutritional and functional properties. Pili pulp oil contains high levels of unsaturated fatty acids, β-carotene, and other carotenoids, making it an attractive raw material for the food, cosmetic, and pharmaceutical industries (Yee, 2016; Pelea, 2012; Chew, 2011). Its applications range from culinary uses as a healthy cooking oil to cosmetic and skincare formulations, and as a functional ingredient in nutraceuticals due to its antioxidant properties (Azrina, 2012).

Despite its potential, the production of high-quality pili pulp oil remains a challenge. Traditional methods, such as manual pressing, are labor-intensive, time-consuming, and result in low oil yields (~12%). Existing village-level mechanical presses offer slightly higher efficiency (~10%), but often produce oil of inconsistent quality, with variable color, odor, and chemical properties (Gupta, 2010). Such limitations restrict the industrial and commercial potential of pili pulp oil, particularly for high-value applications.

Mechanical extraction has emerged as a promising alternative to overcome these constraints. Electrically-driven mechanical presses can increase oil yield, reduce processing time, and standardize product quality (Shakirin, 2010). Moreover, the integration of post-processing techniques, including filtration, distillation, decolorization, heating, and cooling, has been shown to enhance oil properties, such as saponification value, iodine number, peroxide value, and carotenoid content, which are critical for food safety, stability, and industrial applicability (Azrina, 2012; Chew, 2011).

However, there exists a significant research gap: there is currently no small-scale, affordable, electrically-driven mechanical extraction system specifically designed for pili pulp oil that combines optimized operational

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parameters with integrated post-processing. Most studies either focus on manual extraction methods, which are inefficient, or on large-scale commercial processing, which is costly and inaccessible to local small- and medium-scale producers. Consequently, local communities lack a scalable, efficient, and quality-oriented solution to produce pili pulp oil with consistent yield and desirable properties.

Addressing this gap, the present study develops and evaluates a novel mechanical extraction system for pili pulp oil, integrating both optimized extraction parameters and post-processing steps to enhance yield and oil quality. The study specifically aims to:

1. Design, fabricate, and test a mechanical extraction system tailored for pili pulp oil.
2. Determine the optimal operating parameters, including batch size, extraction time, and operating speed, for maximum oil yield.
3. Evaluate the physical, chemical, and nutritional properties of the oil produced by the system.
4. Compare the performance of the developed prototype with manual extraction and existing village-level machines.
5. Assess the economic feasibility of the developed system for small- and medium-scale production.

The outcomes of this research are expected to provide a practical, cost-effective, and scalable solution for local producers, while simultaneously contributing to technological advancement, quality standardization, and economic sustainability in the production of pili pulp oil. By bridging the current research and practical gaps, this study enhances the industrial and commercial potential of pili pulp oil, supporting its broader utilization in food, cosmetic, and pharmaceutical applications in the Philippines and beyond.

MATERIALS AND METHODS

Research Design

This study employed an experimental and developmental research design involving the design, fabrication, testing, and performance evaluation of a mechanical extraction system for pili pulp oil. The study also included post-processing evaluation, oil quality analysis, and economic assessment. The design approach ensured that the machine's specifications met practical operational requirements for small- and medium-scale production.

Design and Fabrication of the Extraction Machine

he mechanical extraction system was designed as a small-scale, electrically driven screw press optimized specifically for the rheological and structural characteristics of pili pulp, which differs significantly from common oilseeds such as coconut, soybean, and sunflower.

The prototype consisted of:

Feeding chamber – for uniform input of pili pulp.

Screw conveyor (pressing mechanism) – crushes the pulp and extracts the liquid.

Motor assembly – AC motor with inverter for speed control.

Filtration unit – removes solid residues.

Post-processing components – including distillation, decolorization, heating, and cooling modules.

The materials were selected based on durability, weight, and food-safety compliance. The screw conveyor and inner shell were made of **hard plastic**, resistant to abrasion and lightweight for ease of installation. The solid

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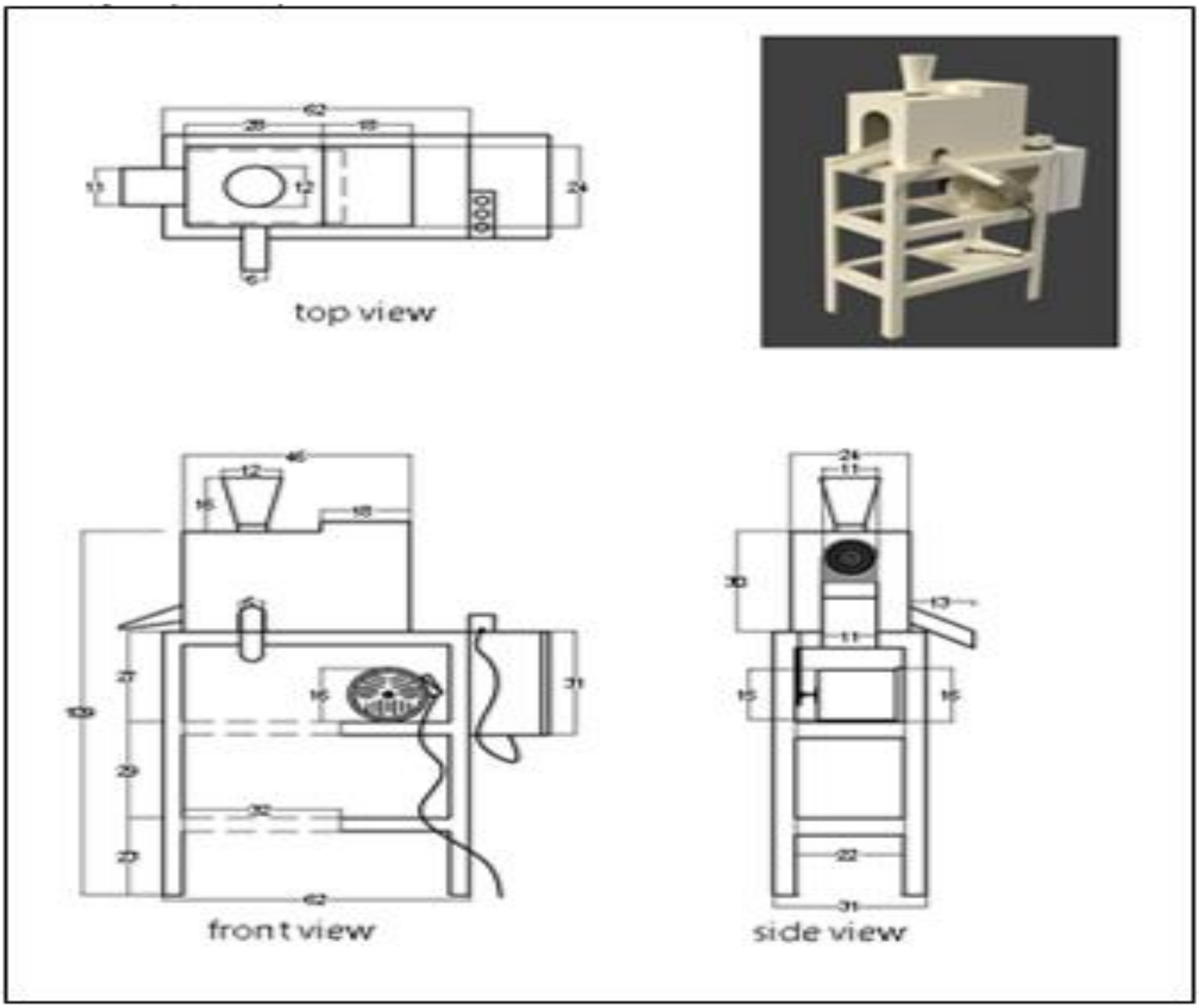
and liquid spouts were made of **stainless steel**, following food industry standards. The machine frame was constructed from **metal** to provide stability and safety.

Figure 1. Schematic Diagram of the Mechanical Extraction System



The schematic shows the feeding port, screw conveyor inside the inner shell, liquid spout, solid spout, motor, and inverter.

Materials

Fresh pili pulp was collected from small-scale growers in Bulusan, Sorsogon, Philippines. All reagents for oil analysis were of laboratory grade and obtained from accredited suppliers. Oil property testing was conducted at the National Institute of Molecular Biology and Biotechnology (NIMBB), University of the Philippines Los Baños.

Experimental Procedure

Pili pulp samples were **soaked in tap water for 2 days** to soften the pulp and facilitate extraction. The softened pulp was cut into smaller pieces to prevent clogging of the feeding port. Samples were then processed using the fabricated extraction machine.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue II, February 2026

The extracted liquid underwent post-processing:

1. **Filtration** – using calcium bentonite or kaolin as the filtering agent.
2. **Distillation** – to remove water content (set at 120°C).
3. **Decolorization** – using a constant heat conductivity cell at 90°C packed with micaceous earth.
4. **Heating** – maintained at 75°C to remove residual moisture.
5. **Cooling** – blower-assisted for 10 minutes to prepare oil for packaging.

Performance Evaluation

The system performance was evaluated based on:

Batch capacity (kg) – maximum pulp weight per extraction cycle.

Extraction time (minutes) – duration for complete extraction.

Operating speed (rpm) – rotational speed of the screw conveyor.

Extraction rate (kg/min) – weight of oil extracted per minute.

Percent oil yield (%) – volume of oil produced relative to initial pulp mass.

Preliminary testing used three different masses (10, 15, 20 kg) and four operating speeds (15, 20, 25, 30 rpm). Each trial was replicated three times to determine optimum operating parameters.

Table 1. Preliminary Testing Results – Mean Volume of Liquid Extract at Different Speeds

Batch Size (kg)	Operating Speed (rpm)	Mean Extraction Time (min)	Mean Volume of Liquid Extract (L)
10	15	27.67	4.81
15	15	35.00	7.29
20	15	41.00	8.50
10	20	11.00	6.07
15	20	16.00	9.13
20	20	20.33	12.17

The optimal parameters were determined to be a 20 kg batch size, 20 rpm operating speed, and 20 minutes extraction time, which were used for all post-processing and final performance testing.

Oil Quality Analysis

The physical, chemical, and nutritional properties of the produced pili pulp oil were evaluated:

Physical properties: color, odor, and specific gravity (sensory observation and measurement).

Chemical properties: saponification number, iodine number, peroxide value, unsaponifiable matter.

Nutritional properties: free fatty acid content, β-carotene, and total carotenoids.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue II, February 2026

All analyses followed **standard laboratory methods** (AOAC, 2016; Shakirin, 2010).

Economic Analysis

The **economic viability** of the extraction system was assessed using:

Rate of Return (ROR) – calculated as the net income relative to total production cost.

Profitability Index (PI) – ratio of gross returns to total project cost.

Payback Period – time required to recover the total investment.

Table 2. Monthly Income Statement for Pili Pulp Oil Production

Particulars	**Quantity**	**Unit Price (Php)**	**Total (Php)**
Raw Materials	2600 g	0.53	1,378
Packaging	975	12	11,700
Labeling	975	3	2,925
Labor Cost	26 days	150	3,900
Contingency	10%	–	1,990.30
Total Production Cost	–	–	21,893.30
Gross Return	–	–	585,000
Net Returns	–	–	563,106.70

The results indicated a ROR of 96%, profitability index of 26.72, and payback period of 2.4 months, demonstrating the economic feasibility of the system.

RESULTS

Performance of the Mechanical Extraction System

The performance of the fabricated mechanical extraction system was evaluated using the optimal parameters determined in preliminary testing: 20 kg batch size, 20 rpm operating speed, and 20 minutes extraction time.

Table 3. Performance of the Fabricated Prototype

Parameter	**Value**
Batch Capacity (kg)	20
Extraction Time (min)	20
Mean Volume of Liquid Extract (L)	12.17
Extraction Rate (kg/min)	0.98
Percent Yield (%)	58.36

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue II, February 2026

The prototype achieved a mean extraction rate of 0.98 kg/min and oil yield of 58.36%, demonstrating high efficiency compared to manual and village-level extraction methods.

Post-Processing Results

Post-processing steps significantly improved the quality of the extracted oil. The results of the processes are summarized in Table 4.

Table 4. Post-Production Process Results

Process	Volume Before (L)	Process Time (min)	Volume After (L)	Percent Recovery (%)
Filtration	12.17	5	11.57	95.08
Distillation	11.57	20	7.67	66.29
Decolorization	7.67	5	7.50	97.83
Heating	7.50	5	7.10	95.11
Cooling	7.10	10	7.10	100

The filtration process removed pulp residues, reducing greenish color and rancid odor. Distillation removed excess water, producing a dark yellow oil without objectionable odor. Decolorization and heating further improved color, while cooling prepared the oil for storage and packaging.

Comparison with Manual and Village-Level Extraction

The extraction efficiency of the fabricated prototype was compared with manual extraction and village-level machines used by pili growers in Bulusan, Sorsogon.

Table 5. Comparison of Extraction Performance

Method	Batch Size (kg)	Extraction Time (min)	Extraction Rate (kg/min)	Percent Yield (%)
Fabricated Prototype	20	20	0.98	58.36
Manual Extraction	20	80	0.25	12
Village-Level Machine	20	60	0.33	10

The fabricated prototype demonstrated approximately 3–4 times higher extraction rate and 48–46% higher yield compared with existing methods. The prototype also reduced extraction time by 60 minutes compared to manual extraction and 40 minutes compared to village machines, confirming its efficiency.

Oil Quality Analysis

The produced pili pulp oil demonstrated a specific gravity of 0.89 (Table 6), which is within the typical range for vegetable oils. This value reflects the density of the oil relative to water and is consistent with oils rich in unsaturated fatty acids.

It is important to note that oil density does not indicate water solubility, as vegetable oils are inherently hydrophobic. However, density influences processing characteristics such as phase separation, filtration efficiency, and formulation behavior in emulsified products.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue II, February 2026

Measured chemical properties include:

Saponification number: 210.83 ± 0.40

Iodine number: 73.5 ± 0.75

Peroxide value: 5.4 ± 0.60 meq/kg

These values indicate that the oil contains fatty acids suitable for industrial and cosmetic applications and exhibits good oxidative stability.

Measured nutritional components include:

β-carotene: 23.6 mg/100 g

Total carotenoids: 56.8 mg/100 g

These results confirm the presence of antioxidant compounds.

Based on these measured characteristics, the oil may be suitable for applications such as cosmetic formulations, soap production, and nutraceutical products. However, specific functional performance in these applications requires further formulation and stability testing.This distinction ensures that the present study reports measured physicochemical properties while identifying potential applications based on established relationships in oil chemistry.

Economic Feasibility

The economic analysis of the developed mechanical extraction system confirmed its financial viability and attractiveness for investment. The system demonstrated a rate of return (ROR) of 96%, indicating a highly profitable operation, while the profitability index of 26.72 suggests that for every peso invested, a return of Php 26.72 can be expected. Additionally, the payback period was only 0.2 years (approximately 2.4 months), reflecting rapid recovery of the initial investment. These results indicate that the prototype is not only technically efficient but also economically feasible, making it highly suitable for small- and medium-scale pili pulp oil production. The combination of improved oil yield, standardized quality, and strong financial performance underscores the potential of the system to support local producers and contribute to the development of a sustainable pili oil industry.

Summary of Key Findings

1. The **mechanical extraction system** produced higher yield, faster extraction, and improved oil quality compared with manual and village-level extraction.
2. **Post-processing steps** significantly enhanced color, odor, and chemical stability of the oil.
3. The **produced oil** had superior physical, chemical, and nutritional properties, making it suitable for **food, cosmetic, and pharmaceutical applications**.
4. Economic analysis confirmed the system as **profitable, cost-effective, and feasible** for commercialization.

DISCUSSION

Performance of the Mechanical Extraction System

The fabricated mechanical extraction system achieved a mean extraction rate of 0.98 kg/min and a percent yield of 58.36%, significantly higher than both manual extraction (0.25 kg/min, 12%) and village-level machines (0.33

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue II, February 2026

kg/min, 10%). This improvement demonstrates that mechanical extraction with controlled operating parameters can enhance the efficiency of pili pulp oil production.

The optimization of operating speed (20 rpm), batch size (20 kg), and extraction time (20 min) was crucial in maximizing the volume of liquid extract while preventing pulp from being expelled without proper crushing. At higher speeds (25–30 rpm), the screw conveyor moved too quickly, resulting in incomplete extraction and lower liquid recovery, consistent with observations in mechanical oil extraction studies (Yee, 2016; Shakirin, 2010).

Effectiveness of Post-Processing

Post-production processes, including filtration, distillation, decolorization, heating, and cooling, enhanced the physical, chemical, and nutritional properties of the extracted oil. Filtration removed pulp residues, reducing greenish coloration and rancid odor. Distillation efficiently removed water, producing a stable oil suitable for storage and commercial applications. Decolorization and heating further improved clarity and stability.

The study demonstrates that integrating post-processing into mechanical extraction not only increases oil quality but also extends its applicability for cosmetic, pharmaceutical, and food industries, aligning with prior findings on the importance of refining processes in edible oils (Gupta, 2010; Pelea, 2012).

Oil Quality Analysis

The produced pili pulp oil exhibited **superior physical, chemical, and nutritional properties** compared with village-produced oil and prior studies.

The **slightly yellowish color** and absence of objectionable odor indicate better sensory quality.

Higher **saponification number (210.83 ± 0.40)** suggests greater suitability for soap production.

Higher **iodine number (73.5 ± 0.75)** indicates a higher degree of unsaturation, increasing **absorbability and anti-allergenic properties**.

Lower **peroxide value (5.4 ± 0.60)** implies improved stability, reducing rancidity during storage.

Enhanced **β-carotene (23.6 ± 0.05) and carotenoids (56.8 ± 0.10)** provide additional nutritional and medicinal value, offering **vitamins A and E**, important for both health and cosmetic applications (Chew, 2011; Azrina, 2012).

These results highlight that **mechanical extraction with integrated post-processing produces oil of higher quality and stability than conventional methods**, providing both commercial and health benefits.

Comparison with Existing Methods

The prototype outperformed both **manual extraction and village-level machines** in terms of yield, extraction time, and oil quality. Manual methods are labor-intensive and time-consuming, yielding only 12% oil with high water content, consistent with reports by local growers. Village-level machines, although electrically driven, still produce lower yields (10%) due to suboptimal design and operating parameters. The fabricated prototype, therefore, addresses the **efficiency and quality gaps** in pili pulp oil extraction, providing a **scalable and sustainable alternative for small- and medium-scale producers** (Yee, 2016; Pelea, 2012).

Economic Feasibility

Economic analysis confirms that the developed extraction system is **highly viable**. With a **rate of return of 96%**, **profitability index of 26.72**, and **payback period of only 2.4 months**, the system represents a **profitable investment** for small- and medium-scale enterprises.

These findings suggest that the integration of mechanical extraction and post-processing can **increase profitability** while reducing labor costs and processing time, addressing the economic limitations of manual and village-level oil production.

Research Gap Addressed

Previous studies on pili pulp oil focused mainly on **manual extraction or basic village machines**, resulting in low yields, long processing times, and inconsistent oil quality (Pelea, 2012; DOST, 2006). The current study **fills this gap** by:

1. Developing a **mechanically optimized extraction system**.
2. Incorporating **post-processing steps** to enhance oil quality.
3. Conducting **comprehensive evaluation** including yield, oil properties, and economic viability.

The study demonstrates that technological intervention can **bridge the gap between traditional practices and industrial standards**, enabling wider commercialization of pili pulp oil.

CONCLUSION

1. A mechanical extraction system for pili pulp oil was successfully designed, fabricated, and tested, achieving higher extraction efficiency and yield than manual and village-level methods.
2. Optimal parameters (20 kg batch, 20 rpm, 20 min) were established, maximizing liquid extract recovery.
3. Integrated post-processing improved physical, chemical, and nutritional properties, producing a slightly yellowish, odorless oil with enhanced β-carotene and carotenoid content.
4. The system proved economically viable, with high rate of return, profitability index, and short payback period, making it suitable for small- and medium-scale production.
5. The developed system addresses key research gaps in pili pulp oil production, offering a scalable, efficient, and commercially promising solution for growers and entrepreneurs.

RECOMMENDATIONS

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

1. **Adoption by Local Producers:** Small- and medium-scale pili growers and entrepreneurs are encouraged to adopt the developed mechanical extraction system to enhance oil yield, improve product quality, and increase profitability.
2. **Further Optimization:** Future studies may explore modifications in screw design, motor capacity, or post-processing techniques to further improve extraction efficiency and oil quality, particularly for larger-scale operations.
3. **Diversification of Products:** The high-quality pili pulp oil produced by the system can be explored for use in food, cosmetic, and pharmaceutical products. Further research on product formulation and shelf-life studies is recommended.
4. **Training and Capacity Building:** Conducting workshops or training programs for local producers on proper operation, maintenance, and safety of the extraction system will ensure sustained and effective utilization.

5. **Sustainability and Expansion:** Economic assessments should be periodically conducted to monitor market trends and ensure sustainable production. Expansion of the system to include kernel oil extraction or integration with other value-added pili products is recommended for broader commercial impact.

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