Performance Optimization and Design Improvements of a Sago (Metroxylon sagu) Pith Extractor for Small Scale Application: A Comparative Evaluation of Efficiency and Capacity

Cindy May C. Belivestre
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

Earl Anthony P. Delfin
Center for Resource Assessment, Analytics, and Emerging Technologies, Caraga State University

Jan Manuel S. Sumando

Neil Caesar M. Tado
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

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Performance Optimization and Design Improvements of a Sago (Metroxylon sagu) Pith Extractor for Small Scale Application: A Comparative Evaluation of Efficiency and Capacity

Cindy May C. Belivestre[1,2], Earl Anthony P. Delfin[2], Jan Manuel S. Sumando[3], Neil Caesar M. Tado[1,2], Aljon E. Bocobo[1,2], May Rose B. Osoteo[1,2], Art M. Dalman[1,2], Juven G. Luzorata[1,2]
[1]Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University, [2]Center for Resource Assessment, Analytics, and Emerging Technologies, Caraga State University
Corresponding author email: ccbelivestre@carsu.edu.ph

Abstract: *The Sago palm (Metroxylon sagu), native to Southeast Asia, is a critical starch resource in rural communities, yet its manual extraction process remains inefficient. This study aimed to enhance the design and operational performance of a sago pith extractor to improve yield, reduce material loss, and increase adaptability in community-based processing. Design improvements included an adjustable rasping blade assembly, an integrated sago pulp collection system, and an improved log-holding mechanism. The enhanced machine was evaluated against a baseline model using locally sourced sago logs provided by the Kaba-ang Livelihood Association in Baan Kilometer 3, Butuan City. Key performance indicators measured were extraction capacity, operational efficiency, and pith loss. Results showed a capacity increase from 307.5 kg/hr to 375.7 kg/hr, efficiency improvement from 89.55% to 97.61%, and reduced losses from 10.44% to 2.39%. The upgraded extractor demonstrates significant potential for improving local starch processing practices, offering a scalable solution for rural livelihoods and promoting sustainable agro-industrial development in sago-producing regions.*

Keywords: Sago pith extraction; Metroxylon sagu; Agro-mechanical design, rasping mechanism

1. INTRODUCTION

The sago palm (Metroxylon sagu), a monocarpic, tropical species of significant agronomic and economic value, is predominantly cultivated in the equatorial peatlands of Southeast Asia, particularly within the regions of Indonesia, Papua New Guinea, and the Philippines. Belonging to the family Arecaceae, this palm exhibits an upright growth habit, attaining heights up to 10 meters and stem diameters of approximately 75 centimeters. During its 7 to 15-year vegetative growth phase, the plant stores a considerable quantity of starch in its trunk, which serves as a key source of food and income for many rural communities [1]

Sago starch is derived from the soft parenchymatous tissues within the trunk and is chemically composed of polysaccharides, primarily amylose and amylopectin. With an energy yield of approximately 355 kilocalories per 100 grams, it provides a high-caloric food source with rapid digestibility, making it suitable for populations engaged in labor-intensive or high-exertion activities. In addition to its energy value, sago contributes to dietary health by promoting gastrointestinal function, supporting immune response, and assisting in skeletal development. As such, the sago palm plays an integral role in food security and agro-based livelihoods in lowland and swamp-forested areas across the Asia-Pacific.[2]

However, traditional methods of starch extraction remain inefficient, labor-intensive, and inconsistent in quality. The conventional process typically involves manual disintegration of the sago pith using a wooden or metal pounder, followed by water-assisted washing and sedimentation to separate starch from fibrous matter. These techniques are time-consuming, physically demanding, and yield suboptimal recovery rates, typically between 25% and 41%. [3] Moreover, inconsistencies in starch quality, including contamination by fibers and impurities, limit its market value. Localized variations in tools and processing approaches further constrain uniformity and scalability. [4]

To address these constraints, mechanical extraction systems have been introduced, offering substantial advantages in terms of throughput, starch purity, and operational hygiene. Mechanized pith extractors significantly reduce human labor, increase productivity, and improve the safety and cleanliness of starch production. [4] Despite these benefits, existing community-scale mechanical extractors exhibit design limitations that hinder operational efficiency. Among the most pressing issues are the lack of adjustability in rasping mechanisms to accommodate varying log sizes, inefficient log stabilization during processing, and discharge systems that contribute to starch scattering losses. These deficiencies not only reduce extraction yield but also complicate machine usability and limit adoption in diverse field conditions.

This study addressed these mechanical limitations through a redesign and performance enhancement of a community-level sago pith extractor. The proposed modifications included (1) an adjustable rasping blade assembly that allowed for better contact with variable log diameters, (2) a reinforced and flexible log holder mechanism for improved alignment and stability, and (3) an upgraded feeding chamber and discharge chute designed to minimize flow obstruction and reduce material loss. These interventions aimed to improve machine adaptability, maximize starch recovery, and reduce process variability under real-world operating conditions.

The primary objectives of the study were threefold: (1) to develop an improved blade design incorporating adjustability and anti-corrosive food-grade materials, along with integrated sago rasp collection features; (2) to evaluate the mechanical performance of the enhanced extractor in terms of extraction capacity (kg/hr), operational efficiency (%), and loss minimization; and (3) to conduct a comparative performance assessment between the enhanced prototype and an existing baseline model under standardized test conditions.

The significance of this engineering intervention lay in its potential to contribute practical, low-cost technological solutions tailored to rural and livelihood-based sago processing systems. The incorporation of anti-corrosive blades enhanced machine longevity and ensured food safety by preventing metal contamination, a critical concern in food-grade processing environments. The flexible log holder facilitated the handling of non-uniform raw materials, reduced downtime due to log repositioning, and improved the continuity of the extraction process. Furthermore, the reengineered feeding and discharge components improved material flow dynamics, reduced clogging, and minimized starch spillage, leading to increased net yield and more efficient resource utilization.

The scope of the study was limited to mechanical design optimization and performance evaluation of the selected subsystems within the sago pith extractor. Chemical, biochemical, or market-based analyses of the processed starch were excluded. Empirical testing was conducted using sago logs sourced from the Kaba-ang Livelihood Association in Baan Kilometer 3, Butuan City. This community-based cooperative engages in the production of traditional sago-derived food products such as palagsing, kinabol, and simumpi, which serve as value-added commodities within the local food economy.

Through this engineering intervention, the study established a foundation for scalable, efficient, and user-adaptable sago processing technologies suitable for broader deployment in under-mechanized agricultural communities.

2. RELATED WORK

2.1 Blade Design and Material Innovation in Sago Rasping Mechanisms

The blade assembly of a mechanical sago pith extractor plays a critical role in determining the quality and efficiency of starch extraction. Tooth spacing significantly impacts rasping performance. In a comparative analysis, the study reported that a blade with 2 cm tooth spacing provided the highest extraction efficiency of 96.12%, whereas a 3 cm spacing yielded the highest extraction capacity at 217.47 kg/h. Meanwhile, the finest pith was achieved with 1 cm spacing, albeit at the cost of lower efficiency. These findings underscore the importance of optimized spacing and blade profile in balancing throughput and pith quality.[5]

Moreover, the choice of materials for rasping blades affects both machine longevity and product safety. Traditional mild steel blades are prone to corrosion and contamination, posing risks to food safety and increasing maintenance costs. The adoption of stainless steel and other food-grade anti-corrosive materials has been highlighted as essential in ensuring hygienic operation and long-term machine reliability.[6] Stainless steel not only resists corrosion but also maintains sharpness over time, ensuring consistent rasping action.

In a more recent development, stainless-steel cylinders were introduced and embedded with steel rods acting as rasping teeth in their improved design. This material innovation proved effective in enhancing the durability of the rasping mechanism under continuous operation. These studies provide design insights foundational to this study's goal of developing an adjustable, food-grade blade system with integrated sago rasp collection. [6]

2.2 Mechanical Performance: Capacity, Efficiency, and Waste Reduction

Evaluating the mechanical performance of sago extraction machines requires comprehensive analysis of throughput, operational efficiency, and loss minimization. Existing literature provides valuable benchmarks for this purpose. A cylinder-type rasper, equipped with optimized teeth design and powered by a 6.5 hp gasoline engine, achieved rasping capacities ranging from 730 to 1009 kg/h. The starch yield was 47.2%, and the loss in waste (hampas) was minimized to 4%. These metrics surpass those of earlier designs powered by 5.5 hp engines with lower throughput and higher waste rates.[7]

In a separate study, the design of a sago rasper machine was enhanced by modifying the hopper configuration and thrust mechanism. This resulted in an improved extraction capacity of 649.38 kg/h, exceeding the industry benchmark of 416.67 kg/h. These findings indicate the significance of not only blade design but also auxiliary mechanisms such as feeding systems in achieving high machine efficiency. [8]

Rotary stirrer-based extraction units also demonstrated promising results. A sago starch extractor was designed with 12 stationary blades operating at 200 rpm. The system achieved an extraction rate of 491 kg/h and a yield of 101 kg/h while minimizing starch loss. These examples provide important references for establishing target performance levels and for validating the improved machine's output. [9]

2.3 Comparative Analysis of Enhanced vs. Baseline Models

Comparative performance assessment is essential for validating design improvements in mechanical systems. Statistical techniques were employed, including analysis of variance (ANOVA) and Tukey's post-hoc test, to determine the significance of differences among various blade configurations. Their methodology provides a sound framework for assessing improvements in extraction efficiency and capacity.[5]

A traditional method of starch extraction was compared in the Philippines with a mechanically assisted process. While manual methods required 10–12 man-days per sago log, the semi-mechanical system reduced processing time by over 50% and achieved a grating capacity of up to 180 kg/hr. The data support the notion that even incremental mechanical enhancements can lead to substantial improvements in processing speed and labor efficiency.[10]

Further, two iterations of a cylinder-type rasper were compared, demonstrating that engine power upgrades and modifications to the cylinder material improved both capacity and starch yield. The newer model, featuring stainless steel cylinders and improved tooth geometry, achieved higher rasping capacities and reduced starch loss compared to earlier versions. [11]

These studies offer established benchmarks and validated methods that are crucial to objectively compare the performance of the enhanced prototype developed in this research against a baseline community-level extractor. By aligning the methodology with these established practices, the reliability and reproducibility of results are strengthened.[12]

3. METHODOLOGY

This study employed a structured engineering design and evaluation methodology to improve the performance of a community-scale sago pith extractor. [11] The process involved the redesign and enhancement of key machine components, followed by prototype fabrication, field testing, and performance evaluation. [13]

A baseline assessment was first conducted to establish reference values, after which targeted mechanical modifications were implemented. The enhanced prototype was subjected to a series of operational tests to assess improvements in key performance parameters, including extraction capacity, efficiency, and material losses.

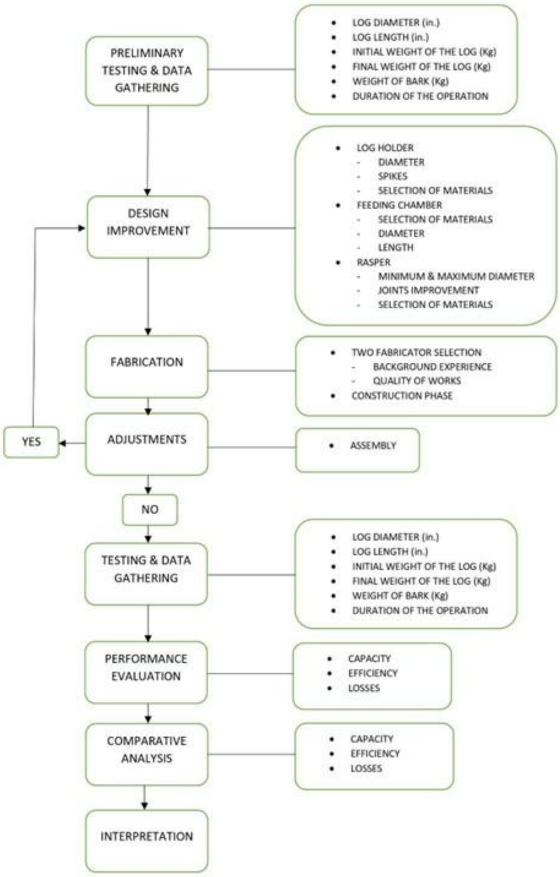

Fig. 1. Process flow

Comparative analysis was then carried out under standardized conditions to validate the effectiveness of the design enhancements.

3.1 Design Development of an Enhanced Blade Assembly and Mechanism Integration

The study began with a performance evaluation of the existing sago pith extractor to establish baseline parameters. Ten (10) sago palm logs of similar physical condition were selected. For each test, the following key metrics were measured: Log diameter (inches), Log length (inches), Initial log weight (kg), Final log weight (kg), Bark weight (kg), Duration of operation (minutes), and Weight of rasped sago pith (kg). This process was repeated across all 10 logs using the original machine setup. The data collected served as the reference against which improvements would later be assessed. Measurements were logged manually using notebooks and calculated with a scientific calculator. A weighing scale, steel tape, and timer were employed to ensure precision in data collection. These values formed the basis for calculating the baseline capacity (kg/hr), efficiency (%), and operational losses (%).

Using the initial performance analysis and identified design limitations, the researchers pursued targeted improvements on three major components of the sago pith extractor:

A. Log Holder Modification

The original log holder lacked adaptability for logs of varying diameters. [14] A flexible design was implemented using a #60 drive chain with welded spikes to improve grip. The adjustability feature allowed secure clamping of logs across a range of sizes, ensuring operational safety and better feed alignment during rasping.

B. Feeding Chamber Enhancement

The original feeding chamber, made from aluminum, was prone to corrosion and posed a food safety risk. [14] It was replaced with stainless steel (SS 304) to ensure hygienic processing and longer operational life. Additionally, the internal diameter was increased from 16 inches to 20 inches to allow smoother feeding of larger logs, optimizing throughput and minimizing jamming.

C. Rasping Blade Redesign

The rasping blade was one of the most critical components. The original non-adjustable, corrosion-prone blade was replaced with a stainless-steel blade system capable of accommodating different log diameters. The blade assembly was mounted on a slot-adjustable frame that allowed tuning of contact depth. This improvement increased the mechanical engagement between the rasp and the log's pith while simplifying maintenance and improving starch purity.

3.2 Mechanical Performance Evaluation of the Enhanced Prototype

Following the design modifications, prototype fabrication was undertaken. Two independent fabricators were selected based on their technical qualifications and project experience to accelerate the construction phase and ensure component accuracy. The fabrication included precision machining of the rasping shaft, welding of the frame structure, and integration of the new blade and feeding chamber systems.

Component specifications and blueprints were reviewed with the fabricators before production. Regular inspections were conducted during the construction phase to maintain dimensional tolerances and build quality. After fabrication, full assembly was carried out and evaluated for physical fit, alignment, and mechanical integrity. [15]

After assembly, dry-run tests were conducted. In cases where component misalignment or fitting issues were observed, adjustments were made. These adjustments primarily involved calibrating the blade assembly position, aligning the log holder to the feeding axis, and checking for uniform rotation of the rasping shaft. If any major incompatibilities were detected, the process reverted to the design improvement phase. Otherwise, the process proceeded to full-scale operational testing.

The same ten (10) sago logs used in the baseline evaluation were processed using the enhanced prototype to maintain consistency. All previous measurement protocols were repeated: Log diameter and length (inches), Initial and final log weight (kg), Bark weight (kg), Duration of rasping (min), Rasped sago pith weight (kg)

Each log was processed individually to avoid overlapping results and to maintain accuracy in evaluating machine performance per test cycle. The same equipment used in the preliminary testing phase (weighing scale, timer, tape measure, containers) was employed to maintain consistency in the data collection process.

Three key performance metrics were used to evaluate the enhanced extractor:

A. Rasping Capacity (Co)

Rasping capacity reflects the amount of sago pith extracted per unit time. It was computed as:

$$C_o = \frac{Average\ output\ (kg)}{Average\ time\ (hr)} \qquad (1)$$

B. Rasping Efficiency (Er)

Efficiency measures the proportion of usable sago extracted relative to the input material:

$$E_r = \frac{Weight\ of\ Extracted\ Sago\ (kg)}{Initial\ \log weight (kg)}\ x\ 100\% \qquad (2)$$

C. Material Loss (%)

Material loss was computed by subtracting the weight of extracted pith and bark from the initial log weight and expressing the difference as a percentage of the original weight.

3.3 Comparative Analysis Between Baseline and Enhanced Models

To assess the effectiveness of the improved design, a comparative performance analysis was conducted between the original baseline and the enhanced prototype. The analysis was based on three parameters: capacity (kg/hr), efficiency (%), and operational losses (%). The evaluation focused on the mean values for each parameter across all ten test logs.

Standardized testing conditions were used to minimize variation. Log samples were matched in terms of size and condition. Processing was conducted in the same ambient environment, and the same operator was employed to eliminate variations due to technique.

Performance improvement was expressed as a percentage change between the baseline and enhanced prototypes. Statistical significance was assessed by evaluating the consistency of improvement across test samples.

The improvements observed in the performance indicators were mapped against the targeted functional enhancements introduced during the design phase. Capacity increases were linked to the enlarged feeding chamber and more effective rasping contact. Efficiency gains were attributed to the adjustability and enhanced material of the blade. Reductions in operational losses were tied to improved log stability and reduced scattering during discharge.

4. RESULTS AND DISCUSSIONS

4.1 Design Improvements of the Sago Pith Extractor

The improved sago pith extractor machine was developed to address specific mechanical limitations observed in the baseline unit. The redesign focused on three critical components: the log holder, the feeding chamber, and the rasping blade. Each component was modified to enhance operational efficiency, improve material handling, and reduce mechanical losses during sago extraction.

(a)

(b)

Fig. 2. Sago pith extractor machine, (a) The baseline machine (b) Improved machine

The baseline machine exhibited constraints in accommodating varying log diameters, inefficient feeding dynamics, and high material losses due to scattering and incomplete rasping. The revised log holder was redesigned using a #60 drive chain integrated with stainless steel nail spikes to firmly secure the log and permit the handling of larger diameters up to 25 inches (63.5 cm). This adaptation addressed the limitations of the fixed log holder by offering greater flexibility and improved grip across a wider log diameter range.

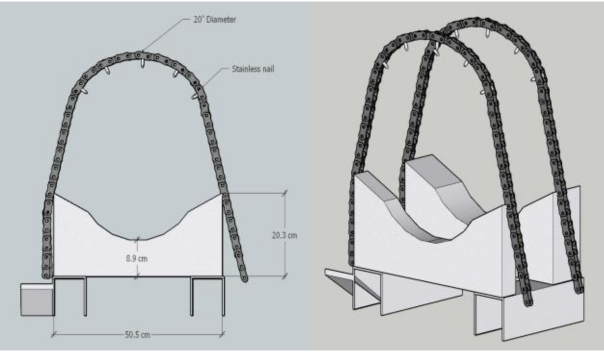

Fig. 3. Log holder design

The feeding chamber was also redesigned to minimize operational losses associated with scattering. The baseline chamber, fabricated from aluminum with a narrow intake width (11.5 cm), was replaced with a wider chamber (24 cm diameter) constructed from food-grade, anti-corrosive stainless steel. This modification not only ensured compliance with food safety standards but also allowed the intake of logs up to 20 inches in diameter, reducing material overflow and enhancing process containment.

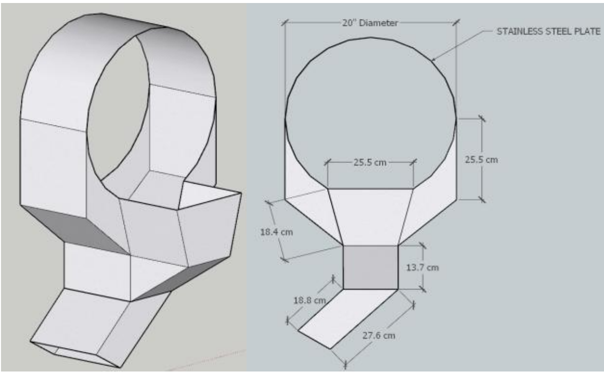

Fig. 4. Feeding chamber design

The rasping blade system, which was originally fixed in diameter and prone to corrosion, was overhauled to include an adjustable design fabricated from stainless steel flat bars. The upgraded rasping mechanism accommodated a range of log diameters from 34.9 cm to 45.7 cm, enabling precise adaptation to varying raw material sizes. Kinematic analysis in CAD software verified the achievable range, ensuring compatibility with the baseline shaft configuration and allowing on-site flexibility without compromising mechanical stability.

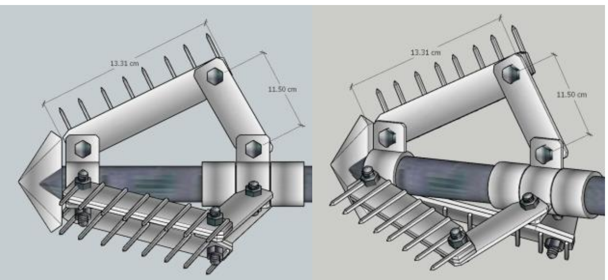

Fig. 5. Rasping blade design

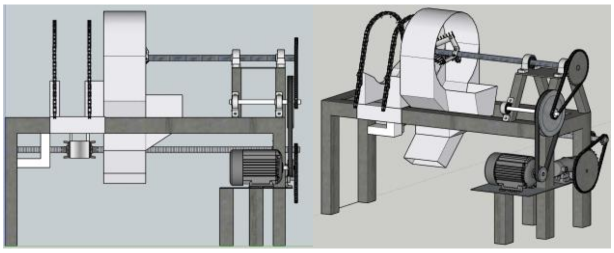

Fig. 6. Improvised sago pith extractor machine design

4.2 Component-Level Design Evaluation

The finalized improvements are summarized in the following tables:

Table 1. Log holder variation

Baseline	Improved
Fixed Log Holder (maximum of 35.6 cm)	Adjustable Drive Chain #60 Log Holder (maximum of 63.5 cm) Anti-corrosive nail spike

Table 2. Feeding chamber variation

Baseline	Improved
Aluminum sheet (11.5 cm width)	Anti-corrosive stainless-steel sheet (24 cm width)
Maximum diameter of 46.6 cm	Maximum diameter of 50.8 cm

Table 3. Rasping blade variation

Baseline	Improved
Fixed rasping blade diameter (35.6 cm)	Adjustable rasping blade diameter; minimum of 35 cm and maximum of 45.7 cm
Metal bar	Anti-corrosive stainless-steel bar
Ordinary nails	Anti-corrosive stainless-steel nails

These design interventions were visualized and validated using AutoCAD modeling tools to ensure engineering compatibility and manufacturing feasibility.

4.3 Operating Time Analysis

Operational tests were conducted using 10 log samples before and after implementing design enhancements. The baseline machine achieved an average operating time of 4.07 minutes per log. This shorter duration was attributed to smaller log dimensions (average diameter = 41.08 cm; average weight = 35.44 kg) and lower maturity, which allowed easier disintegration.

Following the machine upgrade, the average operating time increased to 5.29 minutes. While this duration was longer, it corresponded to the processing of significantly larger and fully mature logs (average diameter = 46.71 cm; average weight = 50.63 kg). The increase in time reflects the enhanced machine's capability to handle more challenging inputs, underscoring its robustness and scalability for real-world applications.

4.4 Performance Evaluation

Losses during sago pith extraction were evaluated before and after the mechanical redesign. Baseline operations incurred an average loss of 3.7 kg per sample log, primarily due to scattering and inefficient feeding. After implementing the improved components, losses significantly declined to an average of 1.21 kg. This reduction is attributed to the optimized feeding chamber and rasping blade alignment, which minimized uncollected material and peripheral ejection.

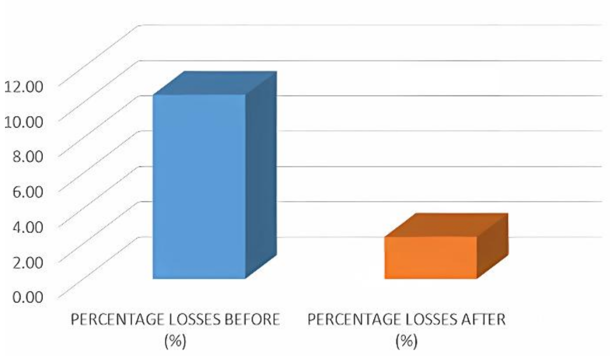

Fig. 7. Loss comparison before and after machine improvements

Percentagewise, extraction losses dropped from 10.44% to 2.39% of the total log mass. This represents an 8.05% absolute reduction, highlighting the effectiveness of the improved mechanical interfaces in optimizing resource utilization and minimizing waste.

The machine's operational capacity increased substantially after the upgrades. The baseline configuration achieved a processing capacity of 307.5 kg/hr, limited by smaller log sizes, high rejection losses, and downtime due to blade adjustments. In contrast, the enhanced extractor processed logs at an average capacity of 375.7 kg/hr - a 22.2% increase.

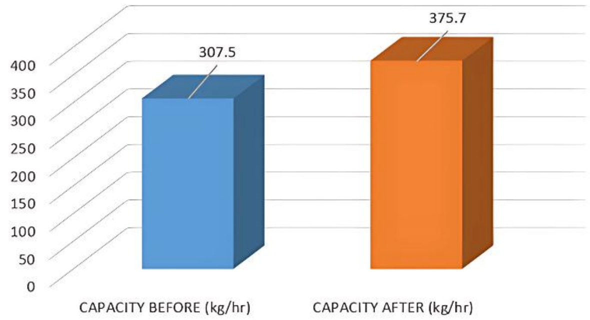

Fig. 8. Operational capacity comparison before and after machine improvements

This improvement reflects the synergy between enhanced grip, consistent feeding, and customizable rasping geometry, all of which contributed to a higher material throughput.

Rasping efficiency, defined as the ratio of extracted pith weight to the log's initial mass, was also assessed. The baseline system demonstrated an average rasping efficiency of 57.71%. After integrating the design modifications, the mean rasping efficiency rose to 61.85%, indicating a 4.14% improvement.

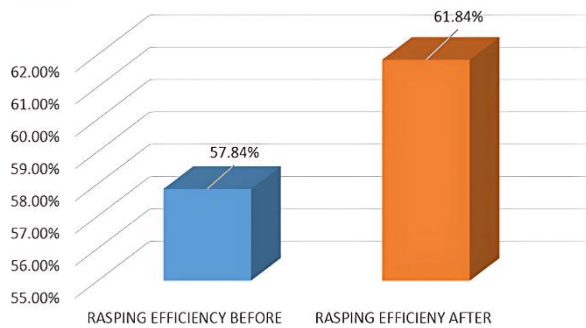

Fig. 9. Rasping efficiency comparison before and after machine improvements

Statistical analysis using a two-tailed t-test confirmed the significance of this enhancement ($p = 0.01 < 0.05$), validating the functional contribution of the upgraded rasper assembly and its adjustability.

Table 4. T-test summary: rasping efficiency comparison between baseline and improved extractor

	Baseline Rasping Efficiency (%)	**Improved Rasping Efficiency (%)**
Mean	57.71	61.85
Variance	9.33	7.53
Observations	10.00	10.00
df	18.00	
t Stat	-3.18	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.73	
P (T<=t) two-tail	0.01	
t Critical two-tail	2.10	

4.5 Comparative Performance Overview

The comparative performance evaluation demonstrated significant improvements across key operational indicators. The extraction yield of sago pith improved from 58% to 62%, reflecting enhanced efficiency in material recovery. Simultaneously, processing losses were markedly reduced from 10% to 2%, indicating a substantial decrease in wasted material. A marginal increase in the weight of residual bark was also observed, which aligns with the more thorough removal of starch content from the pith during operation.

These results suggest that the improved sago pith extractor not only enhanced the volume of usable output but also optimized the overall extraction process. The more complete retrieval of starch from each log contributes to improved resource utilization and value recovery, supporting both economic and operational efficiency for end-users in small-scale agro-industrial settings.

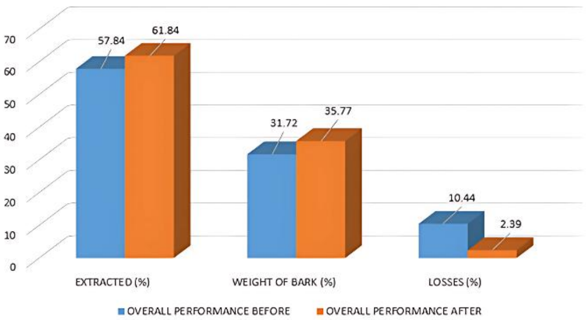

Fig. 10. Overall performance comparison before and after machine improvements

4.6 Dimensional Variability Analysis

To evaluate the adaptability of the enhanced extractor to diverse raw materials, the coefficient of variation (CV) was calculated for diameter and length of processed logs.

Table 5. Coefficient of variation of processed log diameters: baseline vs. improved machine

Samples (10)	Baseline Diameter (cm)	Improved Diameter (cm)
Mean	41.08	46.71
Standard Deviation	0.65	1.44
Coefficient of Variation (CV%)	1.58	3.09

The improved machine processed logs with higher dimensional variability (CV of 3.09% for diameter and 4.17% for length) compared to the baseline (CVs of 1.58% and 2.61%, respectively). These findings demonstrate the improved design's flexibility and broader applicability under field conditions where log sizes are inconsistent.

Table 6. Coefficient of variation of processed log lengths: baseline vs. improved machine

Samples (10)	Baseline Length (cm)	Improved Length (cm)
Mean	36.18	38.60
Standard Deviation	0.94	1.61
Coefficient of variation (CV%)	2.61	4.17

5. CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated the enhancement of the design and performance optimization of a community-level sago pith extractor machine. Compared to the baseline model, which was constrained by limited log accommodation and inefficient component performance, the improved version incorporated critical engineering upgrades including: (1) a flexible log holder with drive chain and spike enhancements; (2) a widened, food-grade stainless-steel feeding chamber; and (3) an adjustable, anti-corrosive rasping blade. These modifications addressed key mechanical limitations identified during preliminary testing, particularly in handling larger log diameters and reducing material losses.

Experimental results revealed substantial performance gains. The improved machine accommodated logs up to 20 inches in diameter, compared to the 16-inch limit of the baseline model. Operational losses were significantly reduced from 10.44% to 2.39%, while rasping capacity increased from 307.5 kg/hr to 375.7 kg/hr. Furthermore, rasping efficiency rose from 89.55% to 97.61%, indicating more effective starch recovery. These improvements support the machine's suitability for deployment in small-scale sago-producing communities, offering a cost-effective and food-safe solution that enhances processing throughput and reduces downtime. The improved design exemplifies the application of the engineering design process in addressing context-specific mechanical challenges. It also highlights the value of integrating food safety standards (i.e., anti-corrosive, food-grade materials) into agricultural processing equipment. The research presents a replicable and scalable solution for local sago-based industries seeking to modernize operations while retaining community-level applicability.

To further optimize machine performance and promote continuous development, the following recommendations are proposed:

1. Modify the height of the rasping blade mounting assembly to align with the vertical center of the feeding chamber. This adjustment is expected to promote uniform rasping action, improve contact efficiency, and minimize operation time.
2. Develop an automated mechanism for adjusting rasping blade diameter to streamline setup and enable real-time adaptability to variable log sizes.
3. Investigate mechanical solutions to recover residual starch at the rear end of the log, where current losses remain unaddressed.
4. Utilize CAD-based motion analysis and finite element modeling to assess structural performance, optimize component geometry, and validate design under dynamic loading conditions.

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