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https://doi.org/10.5109/7395693

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1402-1409, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

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Abstract: *This study presents the design, fabrication, and performance evaluation of a mechanical tuxying tool for abaca fiber extraction, developed through iterative CAD modeling and multi-physics simulation in SolidWorks. Key components, including the blade, roller, and foot press, were optimized using von Mises stress and displacement analyses to ensure structural integrity under field loads. The tool achieved processing capacities of 6.27 kg/hr for Inosa and 2.86 kg/hr for Laylay varieties, demonstrating improved tuxy recovery rates (15.77% and 15.23%) and fiber recovery (8.01% and 9.73%) compared to manual methods, even when operated by a user experienced in manual tuxying but new to the mechanical device. Fabricated with an investment cost of ₱18,000, the tool proved financially viable, offering a short payback period of only 8 days. These findings affirm the tool's potential to enhance labor productivity and efficiency in smallholder abaca farming systems, while design recommendations are proposed to further improve durability and ergonomic performance.*

Keywords: abaca tool; tuxy mechanical tool; tuxy recovery; abaca fiber recovery

1. INTRODUCTION

Abaca (Musa textilis), commonly known as Manila hemp, is a globally significant natural fiber prized for its high tensile strength, biodegradability, and versatility in applications such as textiles, specialty papers, and cordage [1]. The Philippines remains the leading global producer, accounting for approximately 87% of world supply, followed by Ecuador and Costa Rica [2]. Despite the country's dominant position in the global market, the abaca industry continues to face substantial challenges in meeting increasing global demand, primarily due to the labor-intensive and inefficient nature of its traditional fiber extraction processes [3].

The abaca fiber extraction workflow involves three sequential steps: tuxying, stripping, and drying. Tuxying refers to the initial phase of isolating the outermost fibrous layers (tuxy) from the inner leaf sheath. Conventionally performed using manual techniques such as the locknit method, tuxying is a highly repetitive and physically demanding task that limits productivity and introduces inconsistencies in fiber quality (Salmorin & Gepty, 2023). In response, there has been a growing interest in developing mechanized systems to streamline abaca processing. However, most existing innovations focus primarily on stripping mechanisms, with minimal advancements addressing tuxying, especially in the context of small-scale farming systems in geographically isolated and disadvantaged areas (GIDAs) such as those found in the Caraga Region [4].

The need for a portable, affordable, and efficient tuxying tool is critical. Mechanizing the tuxying process could significantly reduce labor requirements, improve processing consistency, and enhance fiber quality, factors that directly affect grading, pricing, and the overall marketability of abaca fibers. Furthermore, enabling on-site processing through such a tool can mitigate logistical challenges, such as transporting unprocessed stalks from dispersed farms to centralized facilities, thereby lowering post-harvest losses and improving cost-effectiveness.

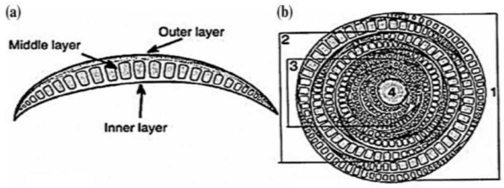


Fig. 1. Cross-section of an abaca leaf sheath (a) Abaca leaf sheath and (b) pseudo-stem. 1, outer group of leaf sheath; 2, middle group; 3, inner group; 4, pith [5]

The present study addresses this technological gap by designing, fabricating, and evaluating a novel mechanical tuxying tool tailored for abaca farmers in the Caraga Region. The research adopts a multidisciplinary approach, integrating principles of mechanical design, materials engineering, and agricultural processing. A combination of finite element analysis (FEA) and multi-physics simulation using SolidWorks was employed to optimize the tool's structural integrity and operational performance. The fabricated prototype was subjected to experimental testing to assess its processing capacity, efficiency, and fiber recovery, compared to conventional manual methods.

This study is scoped to the design, computational modeling, fabrication, and performance evaluation of the abaca tuxying tool using the Laylay and Inosa abaca varieties indigenous to Caraga [6]. The evaluation focuses on metrics such as throughput, efficiency, and fiber recovery. Furthermore, the design targets portability and affordability, making it viable for smallholder farmers in rural and GIDA contexts. However, the study does not extend to large-scale industrial adaptation, and further research is recommended to assess long-term durability, ergonomics, and scalability for commercial operations.

2. RELATED WORK

2.1 Design and development of the abaca tuxy tool

Abaca (Musa textilis), a native fiber crop of the Philippines [7], requires a labor-intensive extraction process consisting of tuxying, stripping, and drying. Among these, tuxying remains the least mechanized. The traditional locknit method involves manually scraping the outer leaf sheath, known as the tuxy, which is laborious and inconsistent in output [3]. Although several studies have proposed innovations in abaca stripping machines [8], the tuxying stage has seen minimal mechanical intervention, particularly in geographically isolated and disadvantaged areas (GIDAs) such as the Caraga Region.

Designing an effective mechanical tuxying tool requires integrating knowledge from mechanical design, materials science, and agricultural engineering. Liu et al. (2014) emphasized that effective design should prioritize ergonomics, material selection, and structural integrity. Recent developments in computer-aided engineering (CAE) tools like SolidWorks Simulation allow designers to perform finite element analysis (FEA) to optimize performance under realistic load conditions. These methods help refine tool geometry, predict mechanical failures, and minimize prototyping iterations, making simulation a critical step in rural mechanization technologies.

2.2 Performance Evaluation: Capacity and Efficiency

The performance of agricultural tools is typically measured through throughput (kg/hr) and recovery efficiency. As reported by [1], abaca fibers are classified into outer (tuxy), middle, and inner sheaths with varying fiber quality, making uniform extraction critical to ensure high market grades. Poor tuxying compromises downstream stripping, reduces usable fiber, and affects the final product's marketability. Standardized tests, such as those following PAES 254:2011, assess processing capacity and tuxy recovery. Prior studies [9] showed that mechanical solutions increase processing uniformity and reduce operator fatigue, but most have focused on stripping, not tuxying.

Moreover, different abaca varieties like Inosa and Laylay exhibit distinct physical properties (e.g., stalk hardness, fiber yield), requiring that mechanical tools be adaptable. These varieties are prominent in the Caraga Region and were used as benchmarks in evaluating tuxying performance in recent field trials.

2.3 Manual vs. Mechanical Tuxying: Comparative Analysis

Comparative studies of manual and mechanical methods underscore key trade-offs in productivity and fiber quality. Manual tuxying, performed solely by hand and knife, allows for selective control during fiber separation but is highly labor-intensive, inconsistent due to operator variability, and prone to fatigue-induced inefficiencies. In contrast, mechanical tuxying enhances uniformity, reduces physical strain, and significantly improves processing speed and fiber throughput. Simbaña et al. [1] documented that uniform removal of the tuxy layer not only improves fiber recovery rates but also enhances grade classification, which is tied directly to pricing in the market.

Performance metrics such as tuxy recovery rate and fiber thickness uniformity are critical in evaluating extraction quality. Experimental results from pilot mechanical tuxying tools in Agusan del Sur [10] suggest improved yield consistency, although long-term field validation is still limited. The current study seeks to fill this gap through both computational and empirical performance assessments.

2.4 Financial Viability of Mechanized Tuxying

The economic impact of mechanization in abaca farming is significant, particularly in GIDAs where labor costs and accessibility issues are pronounced. According to Balda et al. (2021), the feasibility of mechanical tools is often assessed through Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PBP). A study by Mamun et al. [4] affirm that mechanization can double output and reduce labor costs, provided that the machine is cost-effective and portable.

Despite the existence of advanced decorticators and stripping machines, the tuxying stage remains a bottleneck [8]. By enabling on-site fiber separation, a portable tuxying tool reduces transportation burdens and spoilage, offering a favorable return on investment for smallholder farmers. Moreover, improving the consistency and grade of extracted fibers enhances market access and pricing, contributing to rural income generation and sustainable development. [11]

3. METHODOLOGY

This study employed a mixed methods engineering approach that integrates computational modeling, mechanical design, prototyping, and experimental testing. The core objective was to develop a mechanical tuxying tool optimized for abaca fiber processing and to evaluate its performance relative to traditional manual methods. The methodology involved four sequential phases: (1) conceptual and parametric design using CAD and simulation tools, (2) fabrication of the prototype, (3) experimental evaluation of processing performance, and (4) financial analysis of its operational viability.

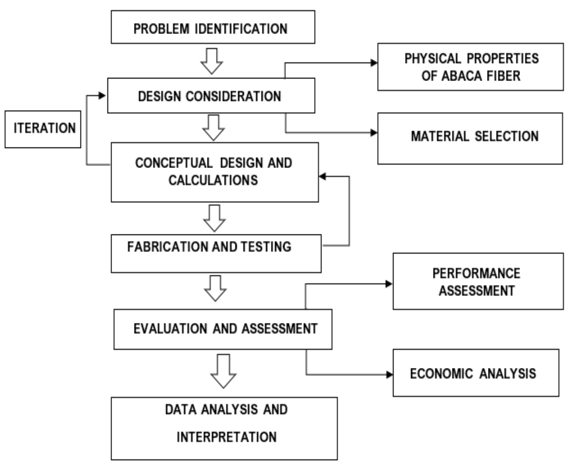


Fig. 1. General framework of the study

Figure 1 illustrates a systematic approach to the development of the abaca tuxy mechanical tool, beginning with problem identification and informed by the physical properties of abaca fiber and material selection. It progresses through conceptual design and engineering calculations, followed by prototype fabrication and performance testing. The tool is then evaluated through performance and economic assessments, leading to data analysis and interpretation. The iterative loop allows for continuous refinement based on testing outcomes, ensuring that the final design is optimized for efficiency, durability, and cost-effectiveness in abaca fiber processing.

3.1 Design and Computational Analysis

The mechanical tuxying tool was conceptualized through iterative CAD modeling in SolidWorks, followed by finite element analysis (FEA) [12] to evaluate mechanical integrity under simulated loading conditions. Core components such as the blade, roller, and housing were analyzed using multi-physics simulation modules to assess von Mises stress, total displacement, and safety factors under operating conditions. The design was optimized to minimize material deformation while ensuring portability, ease of operation, and mechanical reliability in field conditions.

Key design parameters of the mechanical tuxying tool were carefully optimized to enhance performance and usability. The blade geometry was designed to maximize shearing efficiency while minimizing fiber damage during the separation process. The roller diameter and surface texture were engineered to provide effective grip on the tuxy layer, ensuring smooth and consistent feeding. Moreover, the frame assembly was constructed to support ease of operation and field portability, making the tool suitable for deployment in rural and geographically isolated abaca farming areas.

3.2 Fabrication of Prototype

Post-simulation, the mechanical tool was fabricated using locally available materials to maintain cost-effectiveness and ensure replicability in rural contexts. Components were precision-machined and assembled at a partner fabrication shop, with design tolerances derived from simulation results. The materials were selected based on strength-to-weight ratio, corrosion resistance, and cost-efficiency. The final prototype included ergonomic handles, a replaceable blade system, and a manually driven roller mechanism.

3.3 Performance Evaluation

The experimental testing was conducted in Barangay Sinai, Sibagat, Agusan del Sur, using two common abaca varieties cultivated in the Caraga Region - Inosa and Laylay. Field trials compared the mechanical tuxying tool with the conventional manual tuxying method, which involves the use of a hand-held knife for peeling the outer leaf sheath. Performance assessment focused on the following metrics:

Tuxying Capacity Index (kg/hr) - This indicates the rate at which abaca stalks are processed.

$$C_T = \frac{W_{AFT}}{T} \quad (1)$$

Where:

- C_T = Tuxy capacity index
- W_{AFT} = Weight of abaca fresh tuxy (kg)
- T = Time taken for tuxying (hr)

Tuxy Recovery Rate (%) - This represents the percentage of usable fibers obtained after the tuxying process, indicating the efficiency of fiber extraction from the sheath.

$$T_R = \frac{W_{AFT}}{W_{ALS}} \; x\ 100\% \quad (2)$$

Where:

- T_R = Tuxy recovery rate
- W_{AFT} = Weight of abaca fresh tuxy (kg)
- W_{ALS} = Weight of abaca leaf sheath (kg)

Fiber Recovery (%) - A metric indicating the efficiency of tuxying in extracting fiber from the abaca stalk.

$$R_F = \frac{W_F}{W_{PRE}} \; x\ 100\% \quad (3)$$

Where:

- R_F = Fiber Recovery
- W_F = Weight of abaca fresh tuxy (kg)
- W_{PRE} = pre-tuxying weight of the abaca stalk (kg)

Each treatment was replicated three times per abaca variety, and the data were recorded under standardized ambient and operational conditions.

3.4 Comparative Analysis: Statistical Equation

To evaluate the differences in performance metrics between the mechanical and manual tuxying methods, both parametric and non-parametric statistical tests were utilized depending on the distribution characteristics of the data.

Data normality was first assessed using the Shapiro - Wilk test. For datasets meeting the assumption of normality, an Independent Samples t-test was applied to determine if there were statistically significant differences in mean performance values, specifically in tuxying capacity, tuxy recovery rate, and fiber recovery. The t-statistic was computed as:

$$t = \frac{\bar{X}_1 - \bar{\bar{X}}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \; x\ 100\% \quad (4)$$

Where:

- $\bar{X}_1, \bar{\bar{X}}_2$= sample means
- s_1^2, s_2^2 = sample variances
- n_1, n_2 = sample sizes

For data not meeting normality assumptions, the Mann–Whitney U test was employed as a non-parametric alternative. The U-statistics were calculated as:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (5)$$

Where:

- n_1, n_2 = sample size for groups 1 and 2
- R_1 = sum of ranks in Group 1

A significance level of 0.05 was used for all tests. This dual approach ensured robust statistical analysis regardless of data distribution, thereby validating the comparative performance of the tuxying methods.

3.5 Financial Evaluation

A techno-economic analysis was conducted to assess the financial viability of the mechanical tuxying tool. The following financial indicators were computed based on a projected one-year operational scenario:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Benefit-Cost Ratio (BCR)
- Payback Period (PBP)

Investment cost included materials and labor, while returns were calculated based on improvements in fiber recovery and potential market prices per kilogram of abaca fiber.

Economic assumptions followed local price indices and market rates from the Philippine Fiber Industry Development Authority (PhilFIDA).

4. RESULTS AND DISCUSSIONS

This section presents the findings derived from the design validation, experimental testing, comparative performance analysis, and financial evaluation of the developed abaca tuxying mechanical tool. The results are discussed in relation to the study's objectives, with emphasis on the tool's processing capacity, tuxy and fiber recovery performance, statistical significance compared to manual methods, and economic viability. Implications for abaca production systems, particularly in rural and disadvantaged areas, are also highlighted.

4.1 Design and Computational Analysis

The processing of abaca sheaths is prone to fiber breakage, particularly during tuxying, when improper handling or suboptimal tool geometry can compromise fiber integrity. A key design consideration in developing the mechanical tuxying tool was the optimization of the roller-to-blade interface, specifically the clearance and alignment required to facilitate effective separation of the outer sheath without inducing mechanical stress on the underlying fibers.

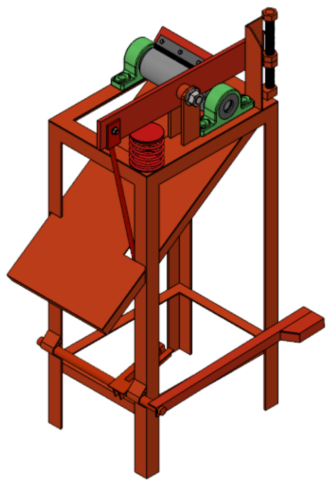
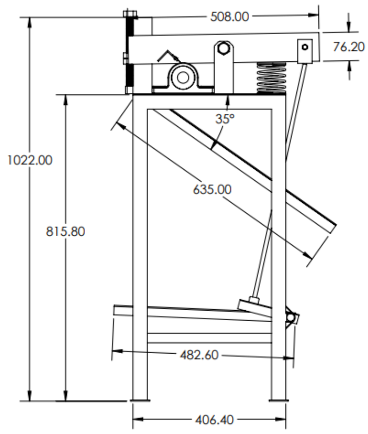
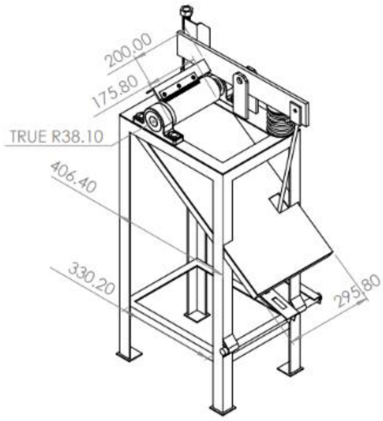


Fig. 2. Abaca tuxy mechanical tool 3d design

The mechanical tuxying tool was designed with a strategically placed foot press opposite the blade to enable single-operator functionality, providing consistent pressure during sheath separation while reducing fatigue. Its performance is influenced by processing capacity, actuation speed, and power input, all optimized for throughput and energy efficiency. SolidWorks simulations guided material and structural choices to ensure mechanical integrity under field conditions. Compliant with PAES 254:2011 standards, the tool aims to enhance labor productivity, minimize fiber damage, and support sustainable abaca farming. An adjustable gap mechanism accommodates sheath thickness variability across abaca varieties, while dimensional specifications, based on sheath widths of 2 to 3 inches, ensure efficient processing aligned with the plant's natural characteristics.



(a)



(b)

Fig. 3. Abaca tuxy mechanical tool 2d design. (a) side view and (b) isometric view

To ensure the mechanical reliability and structural integrity of the abaca tuxying tool, finite element analysis (FEA) was conducted using SolidWorks Simulation. The tool was analyzed under a multi-physics framework, accounting for material properties, applied torque, and mechanical constraints across different components. The analysis focused on evaluating stress distribution and deformation behavior under simulated operational conditions. The simulations focused on two critical design assemblies: (1) the main roller-and-blade system and (2) the frame and handle support structures.

In the structural simulation, two primary materials were employed based on their mechanical performance and application-specific suitability. Figure 4 illustrates that ASTM A36 steel was selected for the tool's frame structure due to its favorable strength-to-cost ratio. With a yield strength of 250 MPa, an elastic modulus of 2.0×10^{11} N/m², and a Poisson's ratio of 0.26, this material ensures stable and rigid support under static and operational loads.

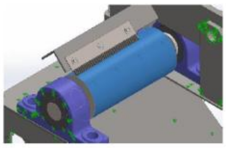
Meanwhile, the AISI 321 annealed stainless steel, presented in Figure 5, was designated for the rotating shaft and torque-driven components, owing to its mechanical resilience under dynamic conditions.

Material Name:	ASTM A36 Steel
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	2.5e+08 N/m^2
Tensile strength:	4e+08 N/m^2
Elastic modulus:	2e+11 N/m^2
Poisson's ratio:	0.26
Mass density:	7,850 kg/m^3
Shear modulus:	7.93e+10 N/m^2

Fig. 4. Solid body component of mechanical tuxy tool subjected to external loads

It possesses a yield strength of 234 MPa, an elastic modulus of 1.93×10^{11} N/m², and a thermal expansion coefficient of 1.7×10^{-5} /K, making it suitable for withstanding rotational stresses and potential temperature fluctuations during field use. A torque of -50 N·m was applied to the shaft within the simulation environment to emulate the real-world torsional forces encountered during tool actuation, ensuring accurate assessment of stress behavior under operational loading.

Material Name:	AISI 321 Annealed Stainless Steel (SS)
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	2.34422e+08 N/m^2
Tensile strength:	6.2e+08 N/m^2
Elastic modulus:	1.93e+11 N/m^2
Poisson's ratio:	0.27
Mass density:	8,000 kg/m^3
Thermal expansion coefficient:	1.7e-05 /Kelvin



Entities:	**1 face(s)**
Reference:	**Face< 1 >**
Type:	**Apply torque**
Value:	**-50 N.m**

Fig. 5. Roller component of abaca tuxy mechanical tool

The blade of the mechanical tuxying tool, measuring 178 mm by 33 mm, was precision-designed to match the average abaca sheath width for consistent separation. Made from AISI 316 stainless steel, it offers high tensile (580 MPa) and yield (172.37 MPa) strength, excellent corrosion resistance, and structural rigidity—supported by its elastic modulus of 1.93×10^{11} N/m² and density of 8,000 kg/m³. Simulated as a linear, isotropic material under the von Mises stress criterion, the blade ensures reliable performance under load. Its bolted configuration allows for easy maintenance while maintaining operational integrity.

Material Name:	AISI 316 Stainless Steel Sheet (SS)
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	1.72369e+08 N/m^2
Tensile strength:	5.8e+08 N/m^2
Elastic modulus:	1.93e+11 N/m^2
Poisson's ratio:	0.27
Mass density:	8,000 kg/m^3
Thermal expansion coefficient:	1.6e-05 /Kelvin

Fig. 6. Blade component of abaca tuxy mechanical tool

The von Mises stress distribution in Figure 7 reveals localized zones of elevated stress within the mechanical tuxying tool, particularly around the foot press mechanism, which endures the highest operational loads during sheath separation. These regions, highlighted in red and orange, exhibit stress magnitudes approaching or exceeding the material's yield strength, signaling potential structural compromise under repeated or cyclic loading.

The displacement analysis in Figure 8 offers essential insight into the deformation behavior of the mechanical tuxying tool under applied operational loads. The simulation reveals that the highest displacement occurs around the foot press mechanism and adjacent components, areas intentionally designed to absorb actuation force during tuxy separation. While the observed deformation remains within the elastic range, indicating structural adequacy under standard conditions, the concentration of displacement in these load-bearing zones raises concerns about potential misalignment, reduced functional precision, or fatigue-induced failure over time.

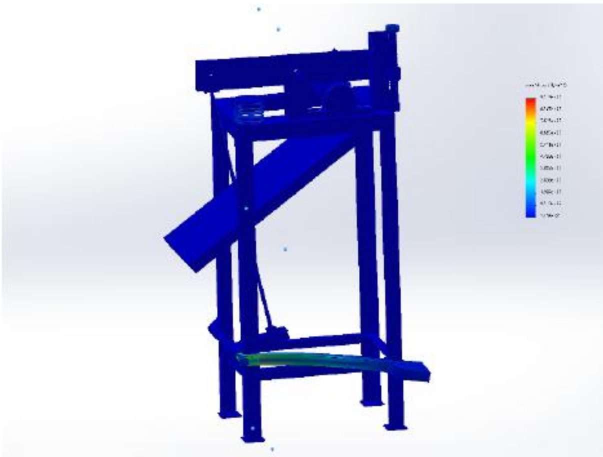


Fig. 7. Von mises stress analysis of the mechanical tool under applied load

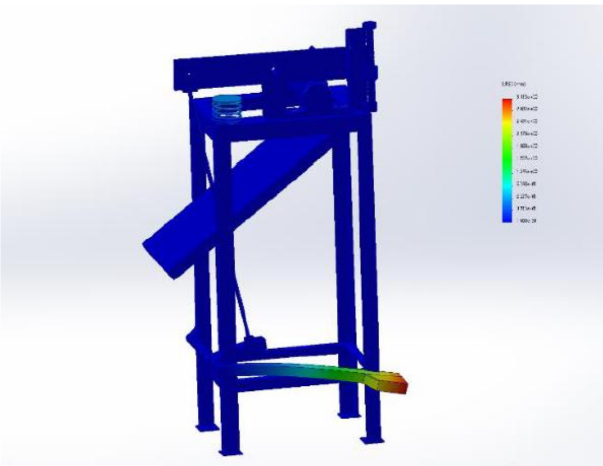
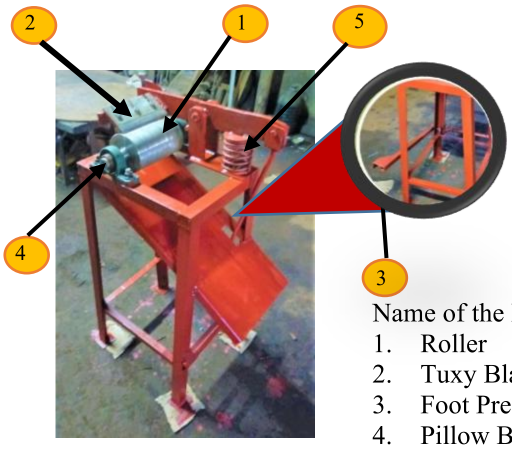


Fig. 8. Displacement analysis of the mechanical tool under applied force

4.2 Fabrication of Prototype

The mechanical tuxying tool was fabricated in accordance with the validated design specifications and SolidWorks simulations, demonstrating high fidelity between the CAD model and the final prototype. The complete tool incorporates key components including the roller, tuxy blade, foot press, pillow blocks, and a spring-loaded mechanism, all engineered for precise and consistent tuxy separation.

The foot press, fabricated from mild steel, enables single-operator actuation, while the pillow block bearings and preloaded spring ensure smooth shaft rotation and adaptive pressure control across varying sheath thicknesses.



Name of the Parts:
1. Roller
2. Tuxy Blade
3. Foot Press
4. Pillow Block
5. Spring

Fig. 9. Fabricated abaca tuxy mechanical tool

Structural integrity was achieved using square tubular steel framing to ensure operator safety and operational stability. The accurate machining and alignment of components, particularly the roller-blade interface, highlights the system's readiness for field deployment. This fabrication phase confirms the practical scalability of the tool and sets the foundation for performance validation in actual abaca processing environments.

4.3 Performance Evaluation

The performance of the developed mechanical tuxying tool was evaluated based on its ability to deliver uniform sheath removal and improved fiber recovery compared to the traditional manual method. The outcomes demonstrate significant improvements in processing quality, consistency, and material utilization.

(a) (b)

Fig. 10. Uniformity of sheath removal (a) manual method and (b) mechanical tuxy tool

The effect of improved mechanical precision is visualized in Figure 10, where the uniformity of sheath strips is compared. Mechanically tuxied strips (b) are more consistent in width, length, and cleanliness, whereas the manually processed ones (a) display substantial variation and visible surface impurities. This consistency is critical for ensuring optimal downstream stripping performance and fiber quality. The inconsistency in manual processing is attributed to variable pressure application and operator fatigue, which often result in under- or over-removal of sheath layers, thereby reducing usable fiber yield.

Quantitative results presented in Figure 11 validate these visual findings A comparative analysis of tuxying thickness and fiber recovery rate between the abaca tuxy mechanical tool and the manual method is presented across the inner, middle, and outer layers of Inosa and Laylay abaca varieties. The data clearly show that the mechanical tool yields more consistent sheath thicknesses, particularly in the middle and outer layers, with reduced variability compared to the manual method, which exhibits significant fluctuations likely due to inconsistent pressure application and operator fatigue.

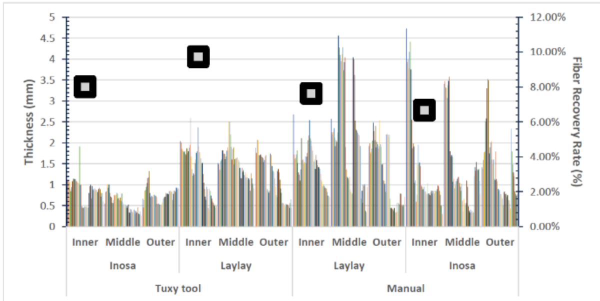


Fig. 11. Comparison of thickness and fiber recovery rate for Inosa and Laylay varieties using the abaca tuxy mechanical tool and manual method

This improved uniformity is critical in preserving fiber integrity and optimizing material use. In terms of fiber recovery, the mechanical tool consistently outperforms the manual method, especially in the outer layer, where recovery rates reach their highest values, approaching or exceeding 9%, due to more precise and controlled separation.

4.4 Statistical Analysis

The statistical analysis comparing the mechanical tuxying tool and manual method revealed no significant differences in overall processing capacity, tuxy recovery rate, and fiber recovery rate at the 0.05 level, as shown in Table 1 using the Mann–Whitney U test due to the non-normal distribution of the raw data.

Although the mechanical method yielded numerically higher tuxy recovery and fiber recovery, the differences were not statistically significant ($p = 0.333$ for both), as was also the case for processing capacity ($p = 0.667$).

The lack of statistical significance may be attributed to the operator's initial unfamiliarity with the mechanical tool, suggesting a learning curve effect. Nonetheless, the mechanical method's comparable performance, even under first-time use, indicates strong potential for improved outcomes with operator adaptation and continued use. This highlights the mechanical tool's viability and scalability in real-world abaca processing scenarios, particularly as user proficiency increases.

The statistical analysis of fiber thickness across different sheath layers for Inosa and Laylay abaca varieties revealed that the mechanical tuxying tool significantly outperformed the manual method in terms of producing more uniform sheath removal, particularly in the outer and middle layers.

For Inosa, presented in Table 2, the mechanical tool showed highly significant differences with lower mean thickness and reduced variability in both the outer layer

($p < 0.001$) and middle layer ($p < 0.001$), confirming improved precision and consistency. While the inner layer also had a lower mean value using the mechanical tool, the result was not significant ($p = 0.146$).

Table 1. Statistical comparison of processing capacity, tuxy recovery rate, and fiber recovery between manual and mechanical tuxying methods.

Dependent variable	Grouping Variable	p-value	Remark
Processing Capacity (kg/hr)	Manual Mechanical	0.667	No significant difference at α=0.05
Tuxy Recovery Rate (%)	Manual Mechanical	0.333	No significant difference at α=0.05
Fiber Recovery (%)	Manual Mechanical	0.333	No significant difference at α=0.05

Table 2. Statistical comparison of fiber thickness across different sheath layers of Inosa abaca using manual and mechanical tuxying methods.

Dependent variable	Grouping Variable	p-value	Remark
Thickness (Outer)	Manual Mechanical	<0.001	Highly significant difference at α=0.01
Thickness (Middle)	Manual Mechanical	<0.001	Highly significant difference at α=0.01
Thickness (Inner)	Manual Mechanical	0.146	No significant difference at α=0.05

For the Laylay variety, as presented in Table 3, the only layer with a statistically significant difference was the middle layer ($p = 0.010$), again favoring the mechanical method. No significant differences were observed in the outer and inner layers for Laylay ($p > 0.05$).

Table 3. Statistical comparison of fiber thickness across different sheath layers of Laylay abaca using manual and mechanical tuxying methods.

Dependent variable	Grouping Variable	p-value	Remark
Thickness (Outer)	Manual Mechanical	0.322	No significant difference at α=0.05
Thickness (Middle)	Manual Mechanical	0.010	Highly significant difference at α=0.01
Thickness (Inner)	Manual Mechanical	0.461	No significant difference at α=0.05

These findings suggest that the mechanical tool excels in delivering consistent and thinner sheath removal in the most critical layers for fiber extraction, enhancing both fiber quality and processing uniformity, despite being operated for the first time by a farmer long accustomed to manual methods.

The performance comparison between manual and mechanical tuxying methods for both Inosa and Laylay abaca varieties highlights a trade-off between processing speed and recovery efficiency. The manual method demonstrated a higher processing capacity, particularly for Inosa at 14.15 kg/hr, which is more than double that of the mechanical tool (6.27 kg/hr).

Table 4. Comparative performance of mechanical and manual tuxying methods

Tuxying Method	Abaca Variety	Processing Capacity (kg/hr)	Tuxy Recovery Rate (Pre- and Post-tuxying rate)	Fiber Recovery (Final Fiber Weight)
Manual	Inosa	14.15 kg/hr	14.65%	6.66%
Mechanical Tool	Inosa	6.27 kg/hr	15.77%	8.01%
Manual	Laylay	3.05 kg/hr	12.98%	7.63%
Mechanical Tool	Laylay	2.86 kg/hr	15.23%	9.73%

This advantage likely stems from the operator's years of experience with manual tuxying, compared to their first-time use of the mechanical tool. However, despite lower throughput, the mechanical tuxying tool outperformed the manual method in both tuxy and fiber recovery rates. For Inosa, the tuxy recovery rate increased from 14.65% (manual) to 15.77% (mechanical), and fiber recovery improved from 6.66% to 8.01%. Similarly, for Laylay, while processing capacity was slightly reduced using the mechanical method (2.86 kg/hr vs. 3.05 kg/hr), it achieved a notable increase in tuxy recovery (15.23% vs. 12.98%) and fiber recovery (9.73% vs. 7.63%). These improvements suggest that the mechanical tool provides more effective and uniform sheath removal, leading to higher material utilization and better fiber yield, which can be further optimized with user familiarization and training.

4.5 Financial Evaluation

The financial analysis of the abaca tuxy mechanical tool demonstrates exceptional economic viability based on key performance indicators. Operating within a machine output capacity range of 2.86 to 6.27 kg/hr, equating to 17.16 to 37.62 kg/day, the tool is designed for a one-hectare abaca farm, with an estimated annual production between 6,267.4 kg and 13,710.3 kg. The initial investment of ₱18,000, coupled with a daily operating cost of ₱350, yields a Net Present Value (NPV) of ₱3,161,387.60 over a 5-year lifespan at a 10% discount rate.

Table 5. Abaca tuxy mechanical tool financial performance

Machine output capacity	2.86 kg/hr - 6.27 kg/hr (17.16 kg/day - 37.62 kg/day)
Area	1 ha
Abaca Production	6,267.4 kg/year - 13,710.3 kg/year
Investment Cost	18,000.00
Operating Cost	350/day
Cost of Abaca fiber	95/ kg
Interest rate	10%
Estimated lifespan	5 years
Net Present Value (NPV)	3,161,387.60
Internal Rate of Return (IRR)	4146.720%
Benefit Cost Ratio (BCR)	8.32
Payback Period	13 days

The Benefit-Cost Ratio (BCR) of 8.32 underscores that every peso invested returns over eight pesos in benefits. Moreover, the Payback Period of just 8 days indicates rapid recovery of the initial capital outlay. These metrics collectively highlight the tool's substantial profitability, short-term return potential, and its transformative capacity to increase farm-level productivity and income for abaca farmers, particularly in rural Philippine contexts where access to capital and labor efficiency are critical.

5. CONCLUSIONS AND RECOMMENDATIONS

This study developed and validated a mechanical tuxying tool for abaca fiber extraction through integrated CAD modeling, multi-physics simulation, and field testing. Structural analysis confirmed that all critical components remained within elastic limits, with high-stress zones identified for reinforcement. The tool achieved a processing capacity of 6.27 kg/hr for Inosa and 2.86 kg/hr for Laylay. Despite the operator's greater experience with manual tuxying, the mechanical tool achieved higher tuxy recovery (15.77% vs. 14.65% for Inosa; 15.23% vs. 12.98% for Laylay) and fiber recovery (8.01% vs. 6.66% for Inosa; 9.73% vs. 7.63% for Laylay).

Recommendations include reinforcing stress-prone regions, refining blade and roller geometry, and enhancing ergonomic design. These improvements aim to bolster durability, efficiency, and user adaptability in real-world abaca farming.

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