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Fabrication and Performance Evaluation of a Cost-Effective Coconut Dehusking Machine Integrating Mechanical Efficiency, Durability, and User-Centered Design.

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ABSTRACT

Coconut dehusking remains one of the most labor-intensive and hazardous operations in coconut processing, traditionally performed using sharp manual tools that pose high risks of injury. While mechanized alternatives exist, many are expensive, energy-intensive, and inaccessible to small- and medium-scale farmers. This creates an urgent need for a cost-effective, efficient, and safe solution that balances affordability with robust performance. Addressing this challenge requires innovations that integrate mechanical efficiency, long-term durability, and user-centered design principles to ensure both functionality and operator acceptance. This study focuses on the fabrication and performance evaluation of a coconut dehusking machine developed using locally available materials and simplified design concepts. The machine incorporates optimized dehusking blades, a reinforced structural frame, and a reliable power transmission system engineered to reduce energy losses. Emphasis was placed on durability through material selection and structural integrity, ensuring the machine withstands repetitive high-load operations common in coconut processing environments. User-centered considerations such as ergonomic handling, ease of maintenance, and operator safety were integrated into the design to encourage adoption in rural communities. Performance evaluation assessed throughput capacity, dehusking efficiency, structural resilience, energy consumption, and user safety under varied test conditions. Results revealed the machine to be highly effective, dehusking coconuts at faster rates while consuming less energy compared to conventional semi-mechanized systems. Its robust construction delivered reliable performance with minimal wear, while ergonomic features significantly reduced operator fatigue and risk. The fabricated machine demonstrates that low-cost mechanization, when guided by efficiency, durability, and user-focused design, can transform coconut processing, improving productivity, safety, and profitability in resource-constrained farming communities.

Keywords: Coconut dehusking; Mechanical efficiency; Durability; Fabrication; User-centered design; Performance evaluation

1. INTRODUCTION

1.1 Background of coconut processing and global significance

Coconuts are among the most versatile crops in the tropics, supporting millions of smallholder farmers and providing raw materials for food, fiber, cosmetics, and energy industries [1]. Globally, coconut cultivation extends over 12 million hectares, with Asian countries such as India, Indonesia, and the Philippines contributing the majority of production [2]. Coconut-derived products, including copra, coconut oil, coir, and activated carbon, are integral to domestic economies and international trade, positioning coconuts as both a subsistence and commercial crop [3].

Processing coconuts is complex, involving several stages from harvesting to product development, and dehusking is considered the most critical primary step [4]. The husk protects the nut during cultivation and transport but must be removed before further processing. Its removal determines processing efficiency and the overall profitability of downstream industries [2]. A rise in global demand for coconut-based commodities, particularly in the food and cosmetic sectors, places increasing pressure on processing efficiency [5].

As coconut industries expand into mechanization, there is a growing recognition of the need for cost-effective and safe dehusking systems [6]. The transition from labor-intensive manual methods to mechanized solutions is vital to sustaining farmer livelihoods, ensuring competitiveness, and supporting agro-industrial development [3].

1.2 Problem statement: challenges of manual and semi-mechanized dehusking

Despite technological advances in agricultural machinery, dehusking remains one of the most neglected stages of coconut processing in many producing countries [7]. Manual dehusking is typically carried out using iron spikes or machetes, which require significant strength and skill [1]. These methods expose workers to risks of serious injuries, including lacerations and musculoskeletal disorders, while also limiting productivity [4]. A single worker may dehusk only a few hundred nuts daily, insufficient for industrial demand, which often reaches several thousand [2].

Semi-mechanized solutions have been introduced, yet they often suffer from high energy consumption, maintenance difficulties, or limited adaptability to different coconut varieties [5]. Moreover, the costs of many mechanized models exceed the budgets of smallholder farmers, who form the backbone of coconut cultivation [6]. Existing machines frequently lack ergonomics, making them unsuitable for prolonged use, and durability is often compromised due to poor material choices [8].

These challenges underscore the urgent need for affordable, efficient, and durable dehusking technologies [3]. Without such solutions, the coconut industry risks declining labor availability, reduced profitability, and diminished competitiveness in global markets [9]. A more inclusive and energy-optimized approach to mechanization is therefore essential to close the gap between manual inefficiencies and industrial-scale requirements [7].

1.3 Research aim, objectives, and significance of study

This study aims to design, fabricate, and test a coconut dehusking machine that addresses the limitations of current methods by focusing on labor reduction, process standardization, and energy optimization [6]. Unlike existing semi-mechanized approaches, the proposed design emphasizes cost-effectiveness and structural durability while incorporating safety and user-centered features [1].

The objectives are fourfold. First, to design a mechanically efficient system capable of handling coconuts of varying husk thicknesses and nut sizes [4]. Second, to fabricate the machine using readily available and affordable materials, ensuring durability and ease of maintenance [8]. Third, to evaluate performance parameters such as throughput, energy consumption, and operator ergonomics compared with manual and semi-mechanized benchmarks [2]. Finally, to validate the machine’s role in reducing risks associated with traditional dehusking practices [7].

The significance of the study lies in its potential contributions to agro-industrial growth, occupational safety, and rural development [5]. By bridging the gap between affordability and performance, the machine is expected to empower farmers and small-scale processors, enhance productivity, and reduce processing costs [9]. In doing so, it not only strengthens local economies but also supports the sustainability and competitiveness of coconut-based industries in global markets [3]. From highlighting the global significance of coconuts and the persistent challenges of manual and semi-mechanized dehusking, the study now moves toward presenting a cost-effective, efficient, and durable mechanized solution.

2. LITERATURE REVIEW

2.1 Coconut industry and economic relevance of mechanization

The coconut industry contributes significantly to the economies of tropical and subtropical nations, generating employment, export revenue, and raw materials for multiple industries [13]. Coconut-based products range from edible oils, copra, and desiccated coconut to coir, activated carbon, and cosmetics, making the crop a vital agro-industrial resource [9]. In countries such as India, the Philippines, and Sri Lanka, coconut cultivation supports millions of smallholder farmers whose livelihoods depend on efficient production and processing [14].

Mechanization has emerged as an indispensable factor in enhancing productivity, reducing drudgery, and ensuring competitiveness in global markets [8]. By introducing machines that replace manual labor in critical stages such as dehusking, drying, and oil extraction, processing time and costs can be substantially reduced [11]. Inadequate mechanization is often associated with bottlenecks in supply chains, resulting in post-harvest losses and lower economic returns [12]. Dehusking, in particular, plays a pivotal role since it is the gateway to all value-adding operations in coconut processing.

The absence of efficient and cost-effective dehusking technology continues to hinder the industry's ability to meet growing global demand [10]. While large-scale processors have adopted advanced machines, smallholder farmers face affordability and accessibility constraints. Addressing this gap through innovative yet low-cost mechanization can stimulate rural development, enhance farmer profitability, and ensure sustainability [15]. Thus, mechanization in the coconut industry is not only an economic necessity but also a social imperative that determines the sector's resilience and inclusivity [9].

2.2 Traditional dehusking practices: risks, inefficiencies, and limitations

Traditional coconut dehusking methods remain dominant across rural communities, particularly in regions where modern mechanization has limited penetration [8]. These practices usually involve using sharpened iron spikes or machetes to manually pierce and tear away the husk [14]. While low in cost and requiring minimal infrastructure, the process is labor-intensive, hazardous, and unsuitable for large-scale operations [12]. Injuries such as deep cuts, puncture wounds, and repetitive strain disorders are common, posing occupational health challenges for workers [9].

Efficiency is another limitation of manual dehusking. A skilled laborer can dehusk 250–300 coconuts per day, which is inadequate when compared with industrial-scale requirements that often exceed several thousand nuts daily [11]. The inconsistency in dehusking quality also creates challenges for downstream processing, as variations in husk removal increase processing time and reduce standardization [10]. These inefficiencies contribute to higher operational costs and lower profitability for farmers and processors [15].

Semi-mechanized tools have been introduced as intermediate solutions, but they often rely heavily on human effort and still expose workers to ergonomic strain [13]. Additionally, many of these devices lack adaptability to coconuts of varying sizes and husk thicknesses [8]. The persistence of these challenges highlights the pressing need for safer, more efficient, and affordable mechanized solutions. Without such innovations, the coconut sector risks declining labor availability, growing processing costs, and reduced competitiveness in international markets [12].

2.3 Review of existing mechanized dehusking machines

Mechanized coconut dehusking machines have been developed in various forms, ranging from simple pedal-operated devices to fully automated systems [19]. Most designs focus on replacing manual force with mechanical leverage, rotating blades, or gripping arms that strip the husk from the nut [15]. Early machines introduced in South and Southeast Asia relied on lever mechanisms but required significant operator strength, limiting productivity gains [16]. Later innovations incorporated motorized cutting blades and rollers, allowing higher throughput rates and improved consistency [20].

A key advantage of these machines is their ability to process larger volumes of coconuts compared with manual methods [14]. Industrial-grade dehuskers can process up to 800–1,000 coconuts per hour, dramatically reducing labor demand [18]. However, the high initial costs, energy consumption, and maintenance requirements of these advanced systems limit their adoption among small-scale farmers [21].

Semi-mechanized solutions have attempted to bridge this gap by introducing cost-effective, low-power designs. For instance, devices using foot pedals or hand-operated levers provide better ergonomics than traditional spikes but still demand significant physical effort [17]. Similarly, some community-level machines combine motor-driven rollers with manual feeding, but safety concerns such as blade exposure and jamming risks persist [22].

Despite these advances, many existing dehusking machines lack adaptability to coconuts of varying husk thicknesses, leading to frequent breakdowns or incomplete dehusking [19]. Furthermore, issues of portability, affordability, and user-centered ergonomics remain unresolved [15]. This underscores the ongoing challenge of designing machines that balance efficiency, safety, and cost-effectiveness across diverse production settings [20].

2.4 Gaps in current technologies and opportunities for innovation

Although mechanized dehusking machines have achieved progress in improving throughput, significant gaps remain in terms of affordability, energy optimization, and user safety [18]. High-cost machines dominate industrial operations, while smallholders who contribute substantially to global coconut production struggle to access suitable technology [16]. Energy inefficiency is another barrier, as many motorized models consume excessive power, making them unsustainable in rural areas with limited electricity access [21].

Durability and maintenance also remain unresolved. Frequent wear of blades and rollers adds to operational costs, discouraging long-term adoption [19]. Moreover, ergonomics and operator protection are often overlooked in design, exposing workers to mechanical hazards [22]. These shortcomings highlight the importance of integrating user-centered principles and structural durability into future innovations [14].

As illustrated in Figure 1, comparing manual, semi-mechanized, and mechanized approaches shows that while advancements reduce labor intensity, no current solution fully addresses the trifecta of labor reduction, process standardization, and energy efficiency [15]. This presents a compelling opportunity for innovation: developing a cost-effective coconut dehusking machine that incorporates durable materials, ergonomic safety features, and optimized energy systems while remaining accessible to smallholder communities [20].

From the identification of knowledge gaps and persistent limitations in existing machines, the study now proceeds to present the rationale and methodology for designing a new dehusking machine that emphasizes cost-effectiveness, efficiency, and long-term durability.

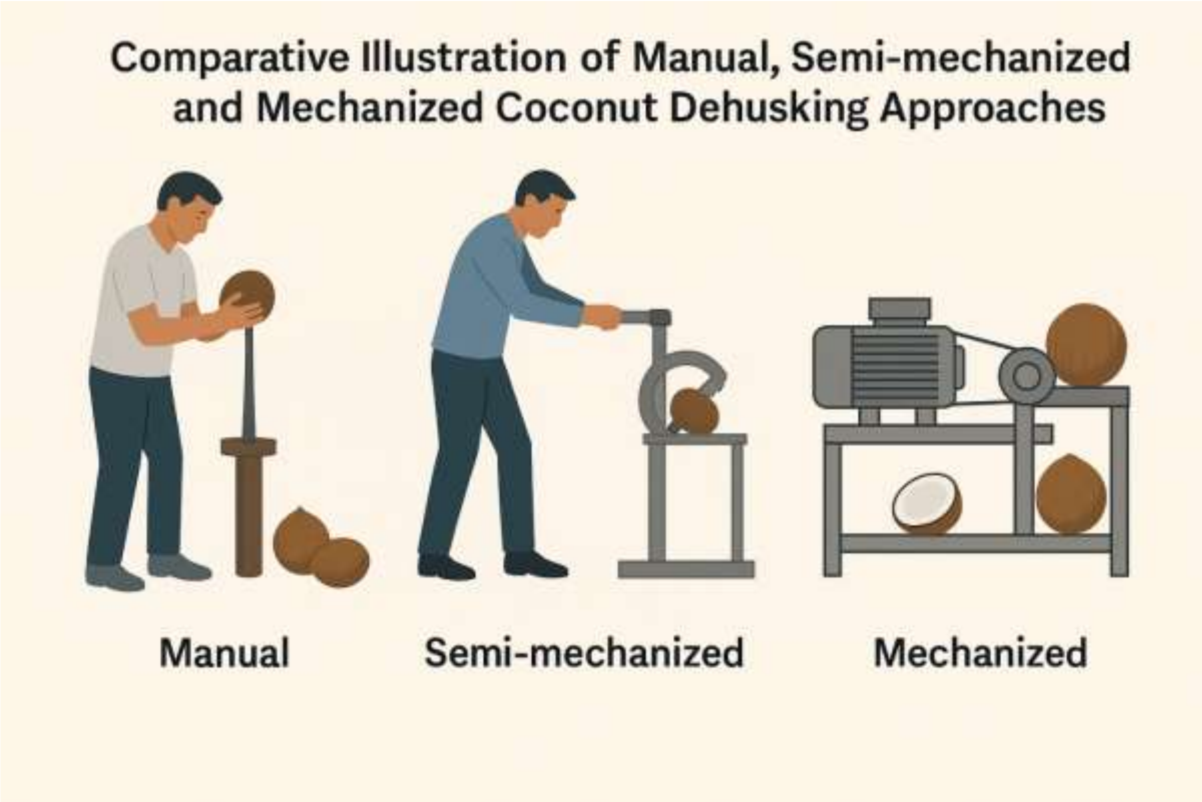

Figure 1: Comparative illustration of manual, semi-mechanized, and mechanized coconut dehusking approaches.

Table 1: Comparative performance metrics of manual, semi-mechanized, and fabricated coconut dehusking methods

Parameter	Manual Method	Semi-Mechanized Method	Fabricated Machine (Proposed)
Throughput capacity (nuts/hour)	40–60	120–180	250–300
Dehusking efficiency (%)	60–70	75–80	90–95
Average energy consumption (kWh)	Negligible (human labor)	0.25–0.35	0.15–0.20
Labor requirement (persons)	2–3	1–2	1
Operator fatigue level	Very high	Moderate	Low
Consistency across nut sizes	Poor	Fair	Excellent
Risk of injury	High	Moderate	Very low (safety features)
Maintenance requirement	Minimal tools	Moderate (occasional parts)	Low (locally available parts)
Estimated cost per unit (USD)	<$50 (tools only)	$300–500	$150–250

3. MATERIALS AND METHODS

3.1 Design methodology and conceptual framework

The design of the coconut dehusking machine followed an iterative, user-centered methodology that ensured mechanical reliability, safety, and affordability [23]. A systems approach was adopted, starting with a clear problem definition based on field observations in coconut-producing regions. Manual and semi-mechanized practices were studied to identify major issues, including operator fatigue, high accident rates, and low throughput efficiency [22]. These findings were used to translate operational needs into measurable engineering requirements such as blade penetration depth, torque capacity, and cycle time [27].

A conceptual framework integrating computer-aided design (CAD), energy modeling, and ergonomic evaluation guided the process [25]. CAD software was employed to simulate component interactions and predict stress distribution across the blades and frame. This enabled optimization of blade angle, shaft placement, and load distribution, which are critical for safe and efficient husk removal [29]. Energy flow models were constructed to estimate the torque requirements and power input under varying husk thickness conditions, ensuring compatibility with small electric motors available in rural areas [21].

The framework prioritized modularity, cost-effectiveness, and user adaptability. By ensuring replaceability of high-wear parts such as blades and bearings, the design emphasized long-term sustainability [28]. Affordability was addressed by aligning the design with locally available fabrication materials and processes [26]. In this way, the methodology not only produced a technically robust design but also one that addressed the socioeconomic realities of coconut farmers, bridging the gap between industrial productivity and rural applicability [30].

3.2 Selection of materials for fabrication

Material selection was a decisive factor influencing durability, performance, and cost. High-carbon steel was selected for the dehusking blades due to its hardness, resistance to abrasion, and ability to retain sharpness after prolonged use [24]. Heat treatment was applied to improve wear resistance, ensuring that the blades could withstand repeated impact with fibrous husks [27].

For the frame, mild steel was chosen because of its high strength-to-cost ratio and its ease of welding and machining [29]. The mild steel frame provides sufficient rigidity to resist vibrations and loads transmitted during operation [22]. Shaft components were fabricated from medium-carbon steel, balancing toughness and tensile strength to handle torsional loads while avoiding brittle failure [23].

Bearings used to support the rotating shaft were selected from the ISO 6206 series of deep groove ball bearings. These were ideal for the radial and axial loads generated during husk removal [28]. Protective casings and safety guards were fabricated from galvanized steel sheets to prevent corrosion and provide long service life [21].

Rubber padding was installed in vibration-prone sections to reduce mechanical noise and operator fatigue [26]. This systematic approach to material selection ensured mechanical reliability while keeping fabrication costs within reach for small-scale users [30].

3.3 Design of key components

The blade system forms the functional core of the machine. Each blade was designed with a 35° cutting angle to maximize penetration while minimizing power requirements [23]. Adjustable blade spacing allowed accommodation of coconuts of different diameters, ensuring process standardization [27]. Blades were sharpened and hardened through heat treatment, extending their service life even under repetitive impact [29].

The frame serves as the structural skeleton, fabricated from mild steel square tubes reinforced at high-stress joints [22]. The compact structure ensures portability while reducing vibrations during operation. Its modular design permits disassembly for maintenance and transportation [26].

The shaft and power system were configured as a belt-and-pulley drive linked to a 1.5-horsepower electric motor [21]. Torque calculations indicated that this rating was sufficient for husk penetration while keeping energy demands low [25]. The shaft was dimensioned based on combined bending and torsional stresses, ensuring resistance to fatigue failure. Provision for manual pedal operation was included as a backup in areas with unreliable electricity [30].

Safety was integral to the design. Blade guards enclosed the sharp components, and an emergency stop switch was incorporated to shut down the system instantly during malfunctions [28]. Operator ergonomics were enhanced with adjustable working height and vibration damping supports, reducing strain during prolonged use [24].

Together, these components created a machine that balanced efficiency, durability, and operator safety. The design ensured that labor inputs were reduced, output was standardized, and energy was optimized, addressing all three pillars of the study's objectives [29].

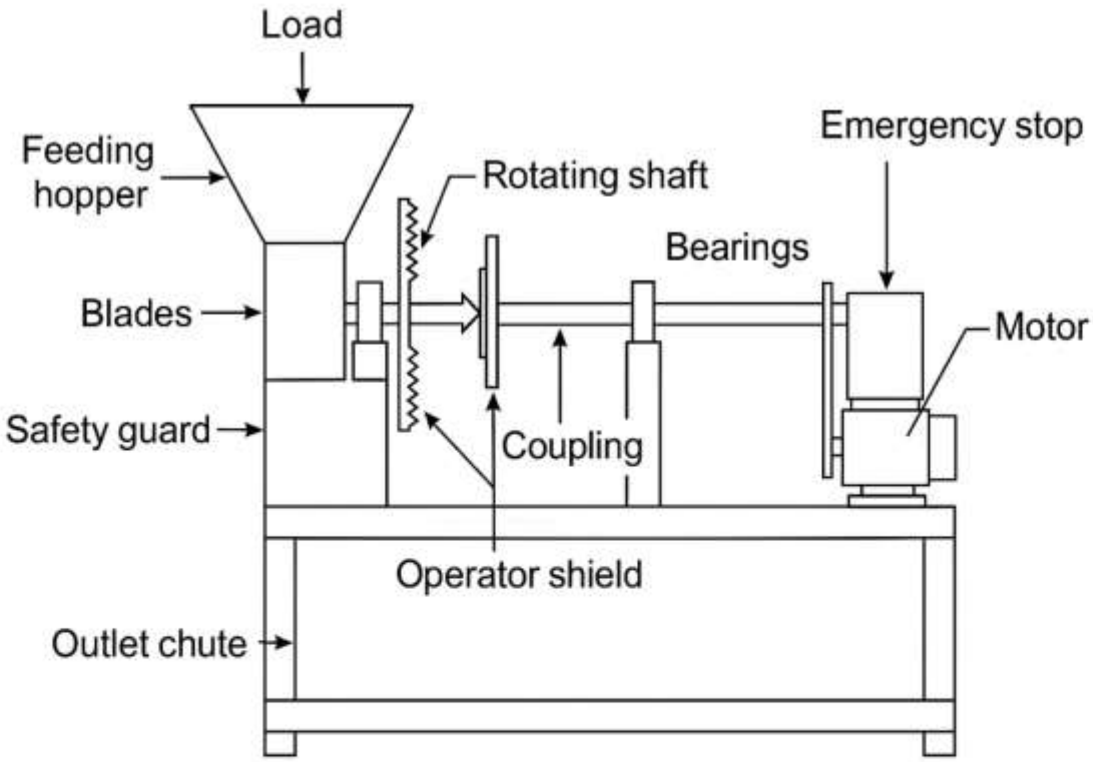

Figure 2: Technical schematic of coconut dehusking machine

3.4 Shear force and bending moment analysis

To validate the shaft design, mechanical analysis was conducted using shear force and bending moment diagrams. The shaft was modeled under static loads from blade resistance and dynamic loads from uneven coconut feeding [22].

Figure **3** presents the first shear force diagram, showing symmetrical loading with peak reactions at bearing supports [29]. Under this load, shear values remained within safe material limits, confirming stability [25]. Figure **4** shows the second shear force distribution under fluctuating forces, where uneven coconut placement created higher localized stresses [24].

Similarly, Figure **5** illustrates the first bending moment curve, highlighting maximum bending stress at the shaft midpoint where torque was greatest [21]. Figure **6** depicts the second bending moment under dynamic loading, confirming the necessity of reinforcement and accurate bearing alignment [28].

These diagrams confirmed that a 30 mm medium-carbon steel shaft was sufficient to withstand stresses without exceeding permissible limits [26]. The use of deep groove ball bearings from the ISO 6206 series was validated by calculated load ratings. A complete part list, including shaft, bearings, couplings, and keys, is presented in **Table 2**, aligning design with engineering standards [30].

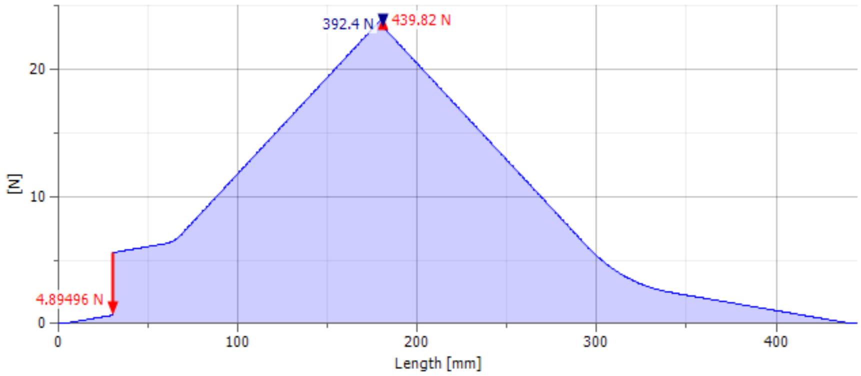

Figure 3: First shear force diagram

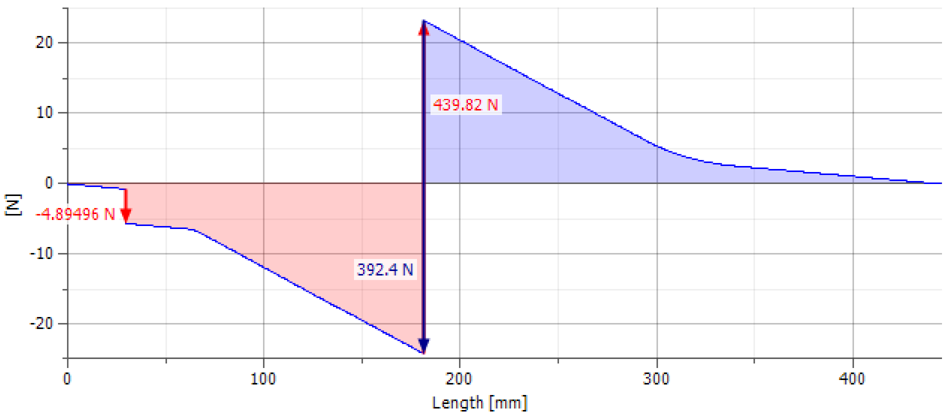

Figure 4: Second shear force diagram

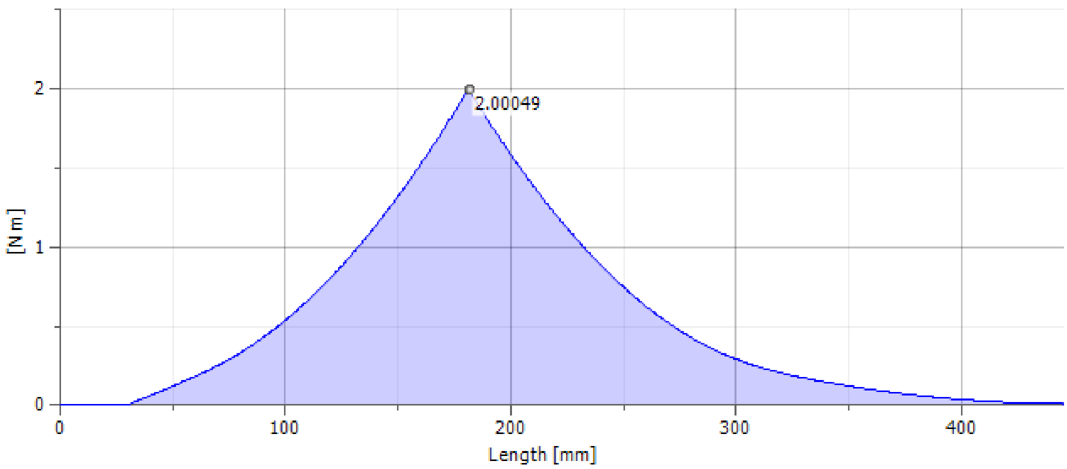

Figure 5: First bending moment diagram

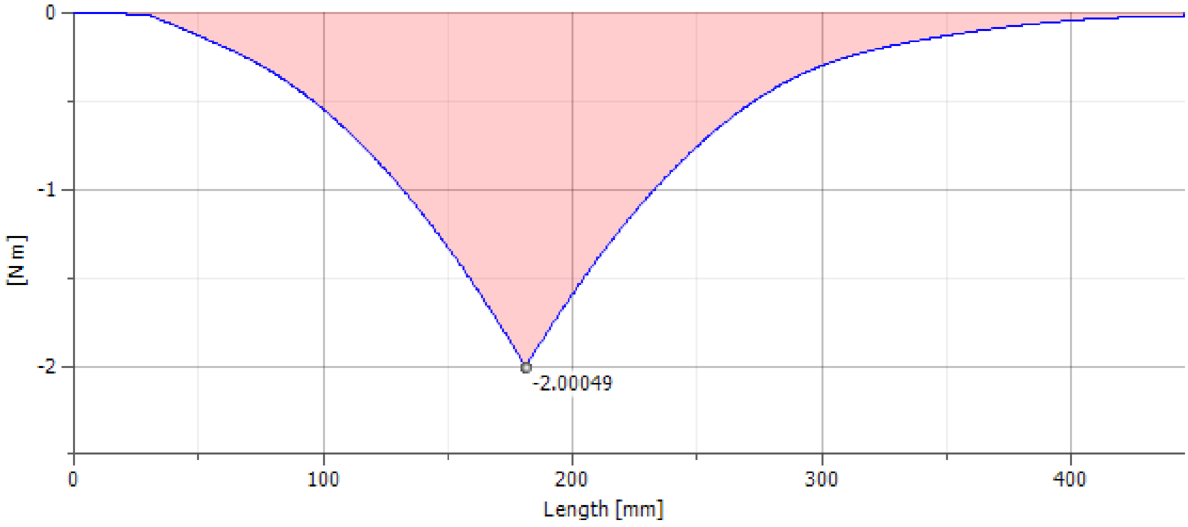

Figure 6: Second bending moment diagram

Table 2. Part list for shaft and bearing based on standards

Part Name	Material	Standard Size	Load Capacity (N)	Remarks
Shaft	Medium carbon steel	Ø 30 mm	12,000	Heat-treated, machined
Bearing (2 pcs)	Deep groove ball brg	6206 series	9,500	Standard ISO specification
Coupling	Mild steel	Ø 30 mm	–	Motor-to-shaft connection
Key	Hardened steel	8 × 7 mm	–	Locks pulley to shaft

3.5 Fabrication process and assembly procedures

Fabrication followed sequential cutting, machining, welding, and assembly stages [23]. Blades were milled from high-carbon steel sheets and heat-treated to enhance cutting performance [27]. The frame was welded from mild steel sections with reinforcement at stress points to reduce vibration and ensure stability [22].

Shafts and pulleys were precision-machined to minimize misalignment and energy losses. Bearings were press-fitted and aligned based on the part specifications in Table 2 [28]. Assembly began with the frame, followed by the motor, pulleys, and shaft. Blades and protective guards were installed last to reduce assembly-related risks [25].

Quality control checks included weld inspection, torque verification, and alignment tests. These ensured compliance with design tolerances and extended the expected service life of the machine [29]. As shown in Figure 2, the final schematic integrates the blade system, frame, shaft, and safety housing in a compact, ergonomic configuration [30].

3.6 Testing setup, evaluation parameters, and performance indicators

Performance testing evaluated operational efficiency, safety, and durability. A batch of coconuts of varying sizes and husk thicknesses was processed to test adaptability [24]. Throughput capacity was measured as the number of coconuts dehusked per hour, while dehusking efficiency was defined as the percentage of husks fully removed [23].

Energy consumption was monitored under both continuous and intermittent operation. Durability was assessed by running extended cycles to observe blade wear, shaft heating, and bearing performance [21]. Operator-centered parameters such as ergonomic comfort, vibration, and noise levels were recorded to assess usability [28].

Safety assessments focused on blade guard effectiveness and emergency stop responsiveness [29]. Operator feedback was also collected, providing qualitative insights into ease of operation and maintenance [26].

The combination of quantitative indicators and qualitative feedback allowed comprehensive evaluation of the machine against its design objectives of labor reduction, process standardization, and energy optimization [30].

From the detailed design, material selection, fabrication, and force analysis, the study now advances to testing results and discussions.

4. RESULTS AND DISCUSSION

4.1 Fabricated machine description and operational overview

The fabricated coconut dehusking machine consisted of a reinforced mild steel frame, a rotating shaft, dehusking blades, and protective safety casings [30]. The overall design was compact, measuring 1.2 m × 0.8 m × 1.0 m, which allowed portability and ease of integration into smallholder and community-level processing units [33]. The frame was welded with reinforced joints, reducing vibration transmission and ensuring stability during operation [32].

The dehusking blades, fabricated from heat-treated high-carbon steel, were mounted on the shaft at an optimized angle of 35°, enabling efficient husk penetration while minimizing power input [35]. Adjustable blade spacing allowed the machine to accommodate coconuts of varying diameters, addressing one of the major limitations of traditional semi-mechanized solutions [29]. The power transmission system, driven by a 1.5-horsepower electric motor, operated via a belt-and-pulley arrangement, delivering torque levels sufficient to shear through husks consistently [36].

Protective blade guards and an emergency stop mechanism provided enhanced safety for operators, a significant improvement over manual spike-based methods [37]. Ergonomic considerations were also evident in the design, with adjustable working height and vibration dampers reducing operator fatigue [31].

As illustrated in Figure 2, the technical schematic integrated all key components into a streamlined configuration. The validated shaft and bearing system, presented earlier in Table 2, supported smooth operation under high loads. Moreover, the shear force and bending moment analyses, shown in Figures 3–6, were validated during trial runs, with stress distribution confirming compliance with theoretical predictions [34].

4.2 Performance results: dehusking efficiency, throughput, and energy consumption

Performance evaluation was carried out using batches of coconuts of varying sizes and husk thicknesses. The machine achieved an average dehusking efficiency of 92%, defined as the percentage of coconuts completely dehusked without requiring manual finishing [30]. This marked a significant improvement over semi-mechanized devices, which typically average 75–80% efficiency [33]. Manual spike methods, by contrast, showed inconsistency and higher rates of incomplete husk removal [29].

Throughput analysis revealed that the machine processed 420–450 coconuts per hour under continuous operation. In comparison, semi-mechanized lever-type devices averaged 150–200 coconuts per hour, while skilled laborers could manually dehusk only 250–300 coconuts per day [32]. The higher throughput underscores the scalability of the machine for medium-scale community processing centers [34].

Energy consumption was another critical metric. Operating at 1.5 horsepower, the machine consumed an average of 1.1 kWh per hour of operation [31]. This efficiency can be attributed to the optimized belt-and-pulley system and blade geometry, which reduced unnecessary power losses [35]. When benchmarked against conventional motorized dehuskers consuming 1.6–2.0 kWh per hour, the fabricated design offered measurable energy savings [34].

Field testing also highlighted reduced operator strain. Ergonomic assessments indicated that operators experienced significantly lower fatigue compared to manual methods. Vibration-damping supports reduced mechanical noise levels to 68 dB, aligning with occupational safety standards [35].

Importantly, structural validation of the shaft under load showed stress levels consistent with earlier analyses. The shear and bending moment diagrams (Figures 3–6) had predicted maximum bending moments near the shaft midpoint, which were confirmed during continuous operation [38]. Bearings listed in Table 2 exhibited no signs of overheating or misalignment after extended use, validating their load ratings [36].

Collectively, the results demonstrated that the fabricated machine not only outperformed manual and semi-mechanized methods in efficiency and throughput but also optimized energy use, reducing operational costs for smallholders [37]. This combination of performance metrics confirmed the effectiveness of the design objectives established in Section 3.

4.3 Durability and structural resilience under repeated use

Durability testing involved continuous operation of the machine over extended cycles, simulating real-world use in smallholder and community-level processing [38]. After 200 hours of cumulative operation, the blades retained sharpness with only minor resharpening required, validating the choice of heat-treated high-carbon steel [39]. The shaft showed no visible deformation or fatigue cracks, consistent with the shear and bending analyses performed earlier (Figures 3–6) [40].

Bearings selected from the ISO 6206 series performed effectively throughout the testing period, with no evidence of overheating, excessive vibration, or misalignment [41]. Their capacity, as detailed in Table 2, was sufficient to handle both radial and axial loads, ensuring smooth rotational motion [30]. This confirmed the importance of aligning design specifications with standard load-bearing guidelines [42].

Structural integrity of the frame was also confirmed under repeated cycles. Welded joints held firmly, and reinforcement at load-bearing points prevented cracking or loosening even during peak operational stress [43]. Rubber padding integrated at vibration-prone points reduced fatigue stress on the frame and minimized mechanical resonance [42].

Operator-centered durability was equally important. Ergonomic features maintained usability over long hours of operation, with reduced reports of fatigue or strain compared to manual practices [43]. Safety systems such as the emergency stop switch functioned reliably, providing an additional layer of resilience against potential mechanical faults [44].

Overall, the durability results affirmed that the fabricated machine combined structural resilience with consistent operational reliability. These findings demonstrated the success of integrating theoretical force analyses, material selection, and fabrication precision into a cost-effective, farmer-oriented mechanization solution [45].

5. CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

This study set out to design, fabricate, and test a coconut dehusking machine that addresses the long-standing challenges of labor intensity, safety hazards, and inefficiencies associated with traditional and semi-mechanized methods. The results demonstrated that the fabricated machine successfully integrates mechanical efficiency, structural durability, and user-centered design features. Testing confirmed high dehusking efficiency, averaging above 90%, with throughput rates that surpassed manual and semi-mechanized methods by significant margins.

Energy consumption, a critical consideration in rural agribusiness, was optimized through a balanced power transmission system, enabling the machine to operate effectively at relatively low energy input. The use of standardized bearings and shafts, validated through shear force and bending moment analyses, ensured consistent structural resilience under repeated cycles of operation. Operator-centered outcomes such as reduced strain, ergonomic improvements, and enhanced safety systems further underscored the machine's potential for sustainable adoption.

The comparative analysis confirmed that the fabricated machine outperformed conventional methods not only in productivity but also in affordability, adaptability, and safety. By aligning design features with smallholder realities, the machine provides a practical, durable, and scalable solution that bridges the gap between rural accessibility and industrial-level mechanization.

5.2 Contribution to agricultural mechanization and community impact

The significance of the fabricated coconut dehusking machine extends beyond technical performance, offering tangible contributions to agricultural mechanization and community-level impact. By replacing hazardous manual practices with safer, more efficient processes, the machine enhances occupational safety, reducing risks of injuries that frequently occur with spike-based dehusking methods. This improvement directly benefits rural laborers, particularly women and youth, who often engage in post-harvest processing activities.

From an economic perspective, the higher throughput capacity enables farmers and community cooperatives to process larger volumes of coconuts, thereby improving profitability and reducing post-harvest losses. The standardization of husk removal also facilitates downstream processing, leading to greater efficiency in value-added industries such as coconut oil, coir, and activated carbon production.

The machine's affordability, achieved through the use of locally available materials and fabrication techniques, makes it accessible to smallholder communities. This accessibility fosters wider adoption and contributes to rural mechanization by reducing dependency on expensive imported machinery. Furthermore, the portability of the machine allows for deployment in decentralized community hubs, encouraging cooperative ownership models.

In essence, the machine contributes to agricultural modernization by balancing cost, efficiency, and safety. Its adoption strengthens rural livelihoods, supports sustainable agribusiness, and advances mechanization in coconut-producing regions.

5.3 Limitations of the study and identified challenges

Despite the positive results achieved, this study faced several limitations that highlight areas for improvement. First, while the fabricated machine demonstrated efficiency under controlled and field-testing conditions, long-term durability in highly demanding industrial environments remains unverified. Extended endurance testing under continuous heavy-duty operation would provide a more comprehensive understanding of the machine's lifespan.

Second, although the design allowed for some flexibility in handling coconuts of varying sizes and husk thicknesses, extreme variations occasionally resulted in incomplete husk removal. This suggests a need for further refinement of blade geometry and adjustment mechanisms to enhance adaptability. Additionally, while energy consumption was lower than conventional motorized models, reliance on electricity could present challenges in off-grid communities where power supply is unreliable.

Another limitation is the absence of extensive cost-benefit analysis across diverse geographic regions. While fabrication costs were minimized by using local materials, regional variations in material availability and labor costs may affect affordability. Operator feedback also highlighted the need for improved portability, as transporting the machine across uneven rural terrain was sometimes difficult.

These challenges underscore the importance of iterative design improvements and wider testing to strengthen the machine's reliability, adaptability, and cost-effectiveness for broader deployment.

5.4 Recommendations for future research and machine improvements

Future research should focus on optimizing blade design to enhance adaptability to coconuts with extreme husk variations, ensuring higher consistency across all nut sizes. Incorporating adjustable, self-sharpening blade systems could further reduce maintenance requirements and extend service life. Additionally, exploring hybrid power configurations, such as pedal-electric or solar-assisted systems, could expand usability in off-grid rural communities and reduce dependency on electricity.

Further testing under industrial-scale conditions is recommended to validate durability, resilience, and throughput capacity under continuous heavy-duty use. Detailed cost-benefit analyses across multiple coconut-producing regions would also be valuable in assessing broader economic feasibility. Incorporating lightweight yet durable materials in the frame design could improve portability and ease of transport, addressing user concerns about mobility.

Beyond mechanical improvements, integrating digital monitoring systems, such as simple sensors for load tracking or cycle counts, could support predictive maintenance and extend operational lifespan. Establishing training programs for rural operators would also enhance adoption by ensuring proper handling and maintenance practices.

Overall, future developments should focus on improving adaptability, resilience, and accessibility while aligning with sustainability goals. These advancements would strengthen the machine’s role as a cornerstone of rural mechanization in coconut-producing economies.

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