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<https://doi.org/10.5109/7395722>

出版情報 : Proceedings of International Exchange and Innovation Conference on Engineering &
Sciences (IEICES). 11, pp.1613-1619, 2025-10-30. International Exchange and Innovation
Conference on Engineering & Sciences

バージョン :

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DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A VILLAGE-TYPE SEMI-AUTOMATED COCONUT (*Cocos nucifera*) MEAT GRATER

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Abstract: This study presents the development and evaluation of a village-type semi-automated coconut meat grater to improve efficiency, safety, and productivity in coconut processing. The machine addresses limitations of existing manual and electric graters by integrating an Arduino-based system with a servo motor for precise coconut positioning and a stepper motor-driven mechanical jack for controlled grating. Tests showed an average grating capacity of 4.60 kg/h, a grating efficiency of 69.21%, and a recovery rate of 65.72%. The prototype demonstrated a low specific energy consumption (0.00387 kWh/kg), underscoring its energy efficiency. This innovation enhances the competitiveness and sustainability of the coconut industry, particularly in countries like the Philippines, where coconut cultivation is economically significant.

Keywords: Coconut Grater; Semi-Automated; Capacity; Efficiency

1. INTRODUCTION

Coconut (*Cocos nucifera*) is a widely utilized resource in homes across many nations worldwide. Every component of the coconut plant is valuable, with some being integral to certain aspects of human existence. The leaves and stems can be used as building materials, while the root has potential medical uses. The coconut husk (mesocarp) is the most commercially viable portion of the fruit. It is processed to make ropes, carpets, geotextiles, and growing [1]. The hard brown shell (endocarp) can reduce transportation fuel and production expenses by processing it into high-quality activated charcoal [2]. Coconut water and kernel are the edible portions of the coconut [3]. It is cultivated in over 90 countries, with Asia and the Pacific accounting for the majority of global production.

The Philippines, Indonesia, India, Sri Lanka, Thailand, Malaysia, and Papua New Guinea collectively account for around 80% of the world's total area cultivated with coconuts [4]. According to the Philippine Statistics Authority, in 2009, the Philippines emerged as the world's second-largest producer of coconuts, trailing only Indonesia, with an impressive output of 19.5 million metric tons. In the recent quarter, spanning April to June 2023, a recorded coconut production (with husk) of 3.41 million metric tons was reported, reflecting an annual increase of 1.5 percent compared to the corresponding quarter in 2022 [5]. Davao (Region XI), Eastern Visayas (Region VIII), and Southern Tagalog (Region IV) are the top three regions in terms of production. 20% of the coconuts produced locally are exported, with the remaining 20% going to consumers within the country. The amount of oil produced is about 90% of the total output. 10% is consumed as fresh nuts, or "buko," or it is processed to make coconut milk (desiccated) and canned in Tetrapak [6].

Coconuts have a variety of benefits and benefits, ranging from cooking and nutrition to skin health, cancer

prevention, beauty products, and even charcoal from the coconut shell [4]. Coconuts are extracted to make coconut oil, a widely used ingredient in the world market for edible oils [7]. Additionally, coconuts are processed to produce drained coconut, which is commonly used in coconut chips and spray-dried coconut milk powder [8]. The demand for coconuts and their products is steadily increasing due to their versatility and numerous health benefits. Coconuts are not only limited to cooking and nutrition, but also cosmetics, medicine, and nutrition [9]. Furthermore, coconuts are a valuable crop in many producing countries, playing a significant role in their economies. The coconut industry has excellent potential for long-term stability and economic viability [10]. With its widespread distribution, multiple uses, and nutritional benefits, the coconut is a prevalent fruit worldwide. The coconut meat in the fruit begins to form after approximately 160 days, when it has reached its full size. The shell starts to harden after 220 days, and the meat fully forms after 300 days. However, for full maturity, 360 days are required [11].

2. MATERIALS & METHODS

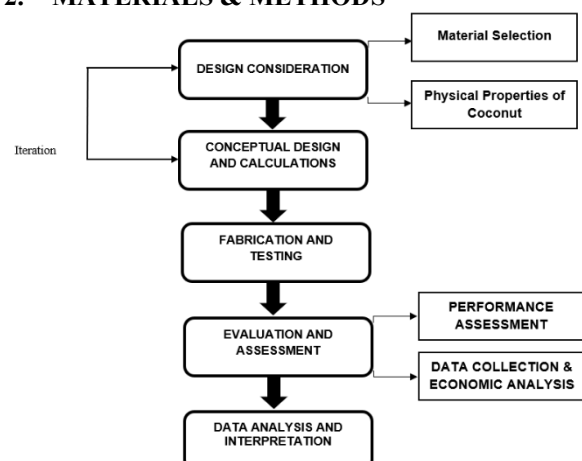


Fig. 1. General Framework of the Study

This methodological framework outlines the process for developing and evaluating a coconut meat grater. It begins with Design Considerations relevant to grating coconut meat, informed by material selection and the physical properties of coconuts. This leads to Conceptual Design and Calculations for the grater's mechanism, with an option for Iteration to refine the design. The next stage is Fabrication and Testing of the grater prototype. Evaluation and Assessment follow, involving Performance Assessment (evaluating grating efficiency, texture, etc.) and Economic Analysis. Finally, Data Analysis and Interpretation are conducted to understand the grater's performance and economic viability.

2.1 Design

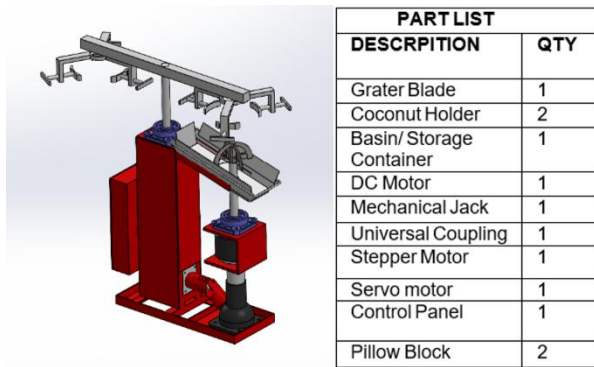


Fig. 2. Semi-automated coconut meat grater (Proposed design)

The semi-automated coconut meat grater is designed with an integrated system of parts intended to function together, providing practical, safe, and easy operation, as shown in Figure 2. The operation begins with the servo motor-powered coconut holder, which rotates to position a coconut precisely above the grating blade. After being synchronized, the stepper motor drives the mechanical jack, raising the coconut to make firm contact with the rotating blade, thereby starting the grating operation. After finishing the grating cycle, the stepper motor changes direction, dropping the mechanical jack to release the coconut from the blade. At the same time, the servo motor turns the holder to position the next coconut for grating. This switching mechanism permits continuous use: while a coconut is being grated, the subsequent coconut can be loaded into the second holder to ensure maximum throughput and minimal idle time. This two-holder system facilitates the smooth grating of several coconuts in succession.

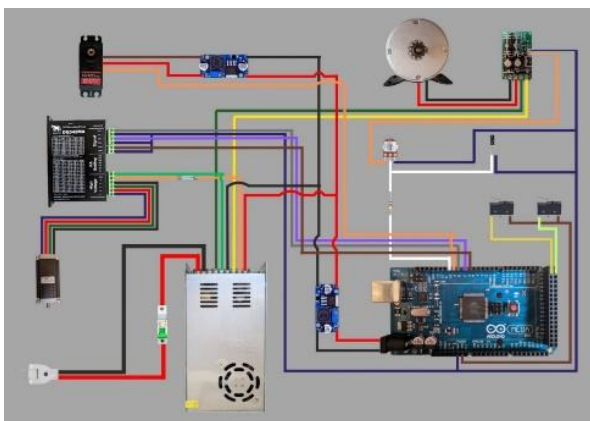


Fig. 3. System Schematic Diagram

The diagram in Figure 3 shows the entire wiring and control system of the semi-automated coconut meat grater. The Brushed DC motor is the primary driving element for the grating process, providing the required speed and torque to effectively shred the coconut meat. A NEMA 23 stepper motor (rated for 30 kg·cm of torque) is used to drive the mechanical jack, which raises and lowers the grating assembly. This provides accurate vertical positioning of the brushed motor and its blade. Raised, the blade is engaged against the coconut; lowered (through counterclockwise rotation), the system resets the blade position, allowing the holder to rotate for the next grating cycle. The stepper motor movement is controlled using a TB6600 stepper motor driver, which receives control signals from the Arduino Mega microcontroller. This provides accurate control of speed and direction. A high-torque servo motor performs a critical function by turning the coconut holder 180 degrees to facilitate automatic repositioning. Once the grating of a single coconut is done, the servo positions the next coconut in place, while the vacant holder slot becomes available for reloading. Power is supplied via a 12V DC, 4.2A power unit, protected by a 10A micro circuit breaker to handle system activation and protection. The use of resistors, jumper wires, buck converters, and other ancillary components provides signal stability and power regulation in all modules. This setup strikes a balance between automation and human intervention, significantly enhancing the efficacy and reproducibility of coconut grating while reducing user effort.

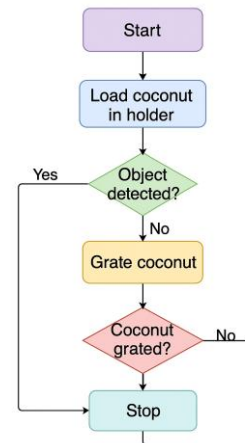


Fig. 4. System Flow Diagram

The flow diagram illustrates the operation of a semi-automated coconut grating machine designed to assess efficiency and reduce manual labor through a coordinated system involving a servo motor, stepper motor, mechanical jack, grater motor, and limit switches, all controlled by an Arduino Mega microcontroller. The process begins with manually loading a coconut into the holder. Operators are given up to one minute to securely place the coconut before the automated sequence starts. Notably, the system features two coconut holder positions within a 180-degree range, allowing the servo motor to alternate between them for continuous operation. Once a coconut is loaded, the servo motor rotates 180 degrees to align one of the holders with the grater blade, which is positioned at the center of the device. This design increases output by providing two coconuts with alternating back-and-forth grating movements. Following the placement of the coconut holder, the stepper motor, which is attached to the

mechanical jack and runs at 300 rpm and 55 revolutions per minute, rotates counterclockwise for 11 seconds. By doing this, the grater motor and blade are successively elevated in the direction of the coconut. A limit switch is triggered when it reaches the top position, signaling that the blade is near the coconut and prepared for grating. At this point, the grater motor (DC motor) starts up and grates the coconut flesh for 40 seconds. When the grating process is complete, the grater motor stops, and the stepper motor reverses its direction to rotate clockwise and lower the blade assembly using the mechanical jack. A second bottom limit switch detects the bottom of the jack. The servo motor rotates once more once it reaches the bottom position, switching to the next coconut holder and beginning the process again. Two coconut holders move back and forth continuously, allowing for continuous operation while one is being grated and the other is being loaded or unloaded.

2.2 Design Considerations

In developing a coconut meat grater, several significant factors had to be taken into consideration to accommodate the varying types of coconuts and enhance machine performance. The machine's capacity had a direct impact on grating speed and power, thereby affecting overall productivity. The motor power output mainly determines the effectiveness of the grating. The optimal blade size and spacing were crucial in reducing resistance, controlling handle movement, and preventing coconut blocks to maximize efficiency. Whereas the force for management had to be decreased to provide smooth and simple handling, the orientation at which the coconut was held was also essential in allowing proper grating.

Regarding user safety and machine durability, key concerns involved incorporating safety features, simplifying cleaning, and ensuring overall maintenance. The use of high-quality, food-grade materials ensured durability and compliance with health regulations. Additionally, a unit with an ergonomic design lessens strain and fatigue for users. After considering these factors, a simplified coconut meat grater was developed to enhance performance, efficiency, and user experience.

Coconut sizing and physical characterization were conducted at Purok 5A, Damayan, Libertad, Butuan City. During the activity, we not only gathered size measurements but also analyzed the physical characteristics of the coconut meat, which were essential inputs for designing the coconut holder and blade mechanism of our grater machine. One of the key properties we considered was the punching force. This mechanical textural property measured the amount of force (in Newtons) required to penetrate or punch through the coconut meat at specific positions, namely the eye, middle, and bottom portions. For this study, we used data from the MOD (Malayan Orange Dwarf) cultivar at 11 months of maturity, which showed punching force values of 18.41 ± 1.53 N at the eye, 36.70 ± 5.72 N at the middle, and 39.12 ± 6.65 N at the bottom [12]. This information was crucial in informing our design decisions, as it enabled us to determine the level of cutting strength, power, and sharpness of the blades, as well as the predicted hardness of the coconut holder, all of which are essential for safe and efficient machine operation. The spring-loaded blade mechanism was another important design element. Finding the ideal

spring that provided the perfect balance of tension and flexibility was essential. Because of this, the blade was able to maintain close contact with the coconut meat, adjusting to different textures and making grating more effective and efficient. To meet the machine's performance criteria, selecting the proper spring was crucial, as it ensured consistency and quality throughout the grating process.

2.3 Engineering Calculations using SolidWorks

The opening frame structure of the semi-automatic coconut meat grater was modeled using AISI 321 tempered stainless steel due to its high corrosion resistance and suitable mechanical properties for food processing equipment applications. The von Mises criterion was used to predict yielding under complex loading situations, assuming the material was isotropic and linearly elastic. The elastic modulus of 193 GPa, tensile strength of 620 MPa, and yield strength of 234.422 MPa were the primary attributes, indicating sufficient stiffness and strength to sustain operating loads. To account for self-weight and potential thermal impacts, the structural study considered the material's high density ($8,000 \text{ kg/m}^3$) and moderate thermal expansion coefficient ($1.7 \times 10^{-5} \text{ /K}$).

The blade was made of AISI 316 tempered stainless steel, chosen for its superior corrosion resistance and mechanical properties in food-grade conditions. The tempered state increased the material's ductility, thereby reducing the likelihood of brittle failure during use. The part was modeled as linear elastic and isotropic, and yielding behavior was examined using the maximum von Mises stress criterion. The blade's rigid, high-strength shape was demonstrated by its yield strength of $1.37985 \times 10^8 \text{ N/m}^2$, tensile strength of $5.5 \times 10^8 \text{ N/m}^2$, and elastic modulus of $1.93 \times 10^{11} \text{ N/m}^2$. To account for deformation, self-weight, and thermal effects, additional properties were considered, including Poisson's ratio (0.3), density (8000 kg/m^3), and thermal expansion coefficient ($1.6 \times 10^{-5} \text{ /K}$). The 3D model displayed a serrated, centrally placed blade system featuring a spring-loaded mechanism that could adapt to varying coconut shell profiles without compromising grating effectiveness, regardless of coconut shape or pressure.

The holder was made of AISI 321 annealed stainless steel because of its outstanding mechanical strength and resistance to corrosion under wet food preparation conditions. Under loading circumstances, the material was simulated to exhibit uniform stress-strain behavior and to be linearly elastic and isotropic. To identify any possible yielding and maintain the component below its elastic limit while in use, the analysis employed the maximum von Mises stress criterion. With a yield strength of $2.34422 \times 10^8 \text{ N/m}^2$, tensile strength of $6.2 \times 10^8 \text{ N/m}^2$, and an elastic modulus of $1.93 \times 10^{11} \text{ N/m}^2$, the material was found to be both elastic and stiff, making it suitable for holding applications. Other variables, including a Poisson's ratio of 0.27, mass density of 8000 kg/m^3 , and thermal expansion coefficient of $1.7 \times 10^{-5} \text{ /K}$, were taken into consideration to ensure performance against mechanical and thermal factors. A symmetrical, clamp-like design intended to securely grasp the coconut while it is being grated is depicted in the 3D model, demonstrating that both structural integrity and food

safety were taken into consideration.

2.4 Stress Analysis (Von Mises)

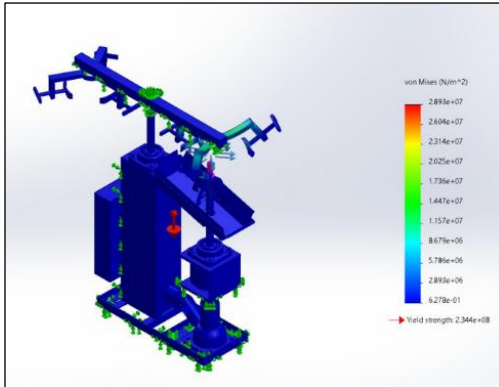


Fig. 5. Von Mises stress analysis of semi-automated coconut meat grater under applied load.

The von Mises stress distribution of the semi-automated coconut meat grater under loading is shown in Figure 5, providing information on the assembly's overall strength. A color scale, with dark blue representing the lowest stress and red representing the highest, was used in the simulation to illustrate the varying degrees of stress. The maximum stress was measured at roughly 2.89×10^7 N/m². This value ensured that the construction was safe within its elastic limit and was significantly lower than the material's yield strength, which is 2.34422×10^8 N/m². Low stress intensities were evident in most parts, as most areas of the grater assembly displayed blue and green colors. No critical stress concentrations were found near or beyond the yield point, indicating that the mechanical design was sound and safe against permanent deformation under the applied conditions.

The total resultant displacement (URES), which highlights the structural response in the form of a color contour map, is based on the total resultant displacement analysis of the load on the semi-automatic coconut flesh grater. At the outer edges of the horizontal crane beam and its extensions, which are further away from the fixed supports, the result displays a maximum displacement of 0.154 mm. Minimal displacement in other regions, with near-zero values ($\sim 1.0 \times 10^{-30}$ mm), confirms the high structural rigidity of the material. This slight yet measurable deflection indicates that the design effectively maintains alignment and dimensional integrity during operation, thereby minimizing the risks of misalignment, fatigue, or failure. The results affirm the grater's mechanical stability and suggest that only minor improvements in localized stiffness may be required for applications with stricter deformation tolerances.

The safety factor analysis of the semi-automated coconut meat grater under operational loading highlights the structure's overall robustness and reliability. The entire assembly was shown predominantly in dark blue, indicating that all components operated with exceptionally high safety factors. According to the color scale, the minimum recorded factor of safety was 8.163, while the maximum reached an unusually high value of 3.734×10^8 , suggesting either simulation default limits or significant overdesign. Such high safety margins implied that the structure could withstand over eight times the applied load before reaching its material limits, far

exceeding typical engineering standards. This demonstrated that the design provided excellent resistance to mechanical failure, fatigue, and unexpected load variations, ensuring prolonged durability and stable performance. Although the results confirmed the mechanical soundness of the grater, the uniformly high safety factors also indicated potential areas for material or weight optimization, should future designs require improved efficiency or reduced cost.

2.5 Fabrication

Two fabrication sites were utilized for this study: Torralba's Machine Shop in Butuan City, Agusan del Norte, and Comet Machine Shop in Los Angeles, Agusan del Norte. The frame of the system was initially crafted at Torralba's; however, due to time constraints and the fabricator's inability to complete the blade and holder components, we looked for an alternative. The Comet Machine Shop accepted the task and confirmed they could fabricate the blade and holder. The designated machinist technicians from both shops worked closely with us, providing valuable assistance and recommendations on material selection, fabrication procedures, and necessary design adjustments to ensure the system's successful completion.

2.6 Evaluation & Testing

2.6.1 Pre-evaluation and performance testing

A pre-evaluation was conducted before the experimental performance evaluation to ensure the functionality of the Semi-Automated Coconut Meat Grater. During this phase, necessary adjustments were made to the System to minimize potential biases in the actual evaluation and to verify that the tool operated according to its intended purpose, thereby supporting more reliable data collection.

2.6.2 Sample Preparation

In the preparation phase before grating, coconuts were sourced from the public market in Ampayon, Butuan City. Samples were randomly selected based on the available sizes at the time of purchase. Figure 6 shows the coconut samples used in the study.



Fig 6. Procurement of coconut samples at Ampayon Market, Butuan City, used for collecting data

2.7 Data Gathering and Testing Analysis

Data collection and analysis were conducted to evaluate the machine's performance based on preset measures, including grating capacity, efficiency in grating, recovery rate, energy consumption, and working time. The testing was conducted using data acquisition from multiple trials with a fixed quantity of coconuts to obtain values for all aspects of performance. Statistical analysis of the received data was performed using averaging and comparison of energy consumption per kilogram of grated coconut. The evaluation affirmed the machine's effectiveness and highlighted areas where it needs

improvement for the reliability and effectiveness of the semi-automated coconut meat grater.

3. RESULTS & DISCUSSION

This chapter presents the results obtained from testing and evaluating the Semi-Automated Coconut Meat Grater. The discussion includes analysis and the machine's performance based on key metrics such as coconut size processed, grating capacity, grating recovery, grating loss, overall grating efficiency, power consumption, and operational characteristics. The interpretation of these results is directly linked to the research objectives, and where relevant, the machine's performance is benchmarked against applicable Philippine Agricultural Engineering Standards (PAES). Figure 7 provides a visual representation of the Semi-Automated Coconut Grater Machine, offering a visual context for the performance data discussed within the chapter.



Fig. 7. Fabricated Semi-Automated Coconut Grater Machine during Testing

3.1 Coconut Samples

Each trial involved ten randomly selected coconuts from the same batch to assess variability in physical dimensions. Diameter, circumference, length, and width were measured using a calibrated Vernier caliper and measuring tape. Mean values from three independent trials were computed to evaluate size consistency.

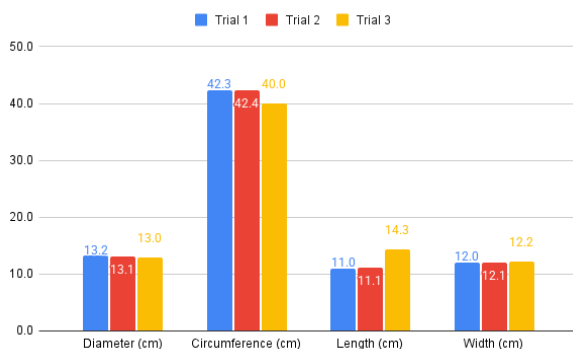


Fig. 8. Comparative Analysis of the Physical Dimensions of Coconuts (Diameter, Circumference, Length, and Width) Across Experimental Trials

Results (Fig. 8) indicate that most samples fall within the medium size range (40–44 cm diameter), matching the design specifications of the holder mechanism. Trial 1 recorded eight medium-sized coconuts, Trial 2 nine, and Trial 3 seven, with smaller specimens present in all trials. No large coconuts (≥ 45 cm) were observed, confirming

compatibility with the current design but highlighting potential limitations for smaller sizes.

3.2 Grating Capacity

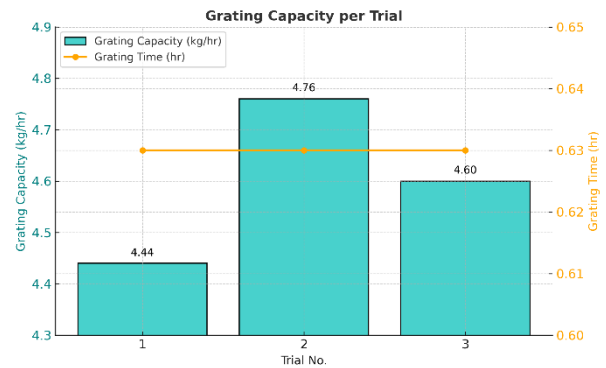


Fig. 9. Coconut Grating Capacity

Fig. 9 shows the coconut grating capacity of the coconut grater, indicating the amount of coconut meat processed by the machine per unit of time. In the first three trials, 10 coconuts were grated, and the production of grated meat varied from 2.8 kg to 3.0 kg. The time used for grating was also relatively constant across trials, with an average of 0.627 hours. According to these values, the capacity of the machine to grate was determined, with Trial 1 recording 4.44 kg/h, Trial 2 achieving the highest at 4.76 kg/h, and Trial 3 recording 4.60 kg/h. The mean grating capacity of all the trials is 4.6 kg/hr, meaning the machine can consistently grate about 4.6 kilograms of coconut meat per hour under normal conditions.

The differences in grating capacity may be related to the limited variation in coconut size, uniform alignment of coconuts, and operator handling. The results of the experiment generally demonstrate that the machine produces consistent and effective results, making it suitable for both home and small-scale industrial use.

3.3 Grating Efficiency and Recovery

Fig. 10 presents the grating efficiency and recovery performance of the developed coconut grating machine across three trials. The grating efficiency ranged from 66.35% to 70.73%, with a mean of 69.21%. The grating recovery varied between 61.61% and 68.24%, with an average of 65.72%. Trial 1 exhibited the lowest values for both parameters, whereas Trial 2 attained the highest, indicating improved operational consistency and handling.

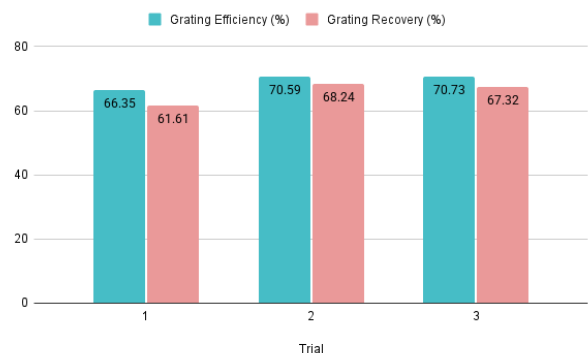


Fig. 10. Grating efficiency and recovery performance of the coconut grating machine across three trials.

The close alignment of efficiency and recovery trends suggests that the machine maintained stable performance in converting coconut meat into grated form. Minor variations may be attributed to differences in coconut maturity, moisture content, or feeding conditions. Overall, the results demonstrate that the machine effectively utilized approximately two-thirds of the coconut mass, confirming its operational reliability and potential for further optimization to minimize losses and enhance output yield.

3.4 Grating Loss

As shown in Figure 11, the grating loss values across the three trials exhibited noticeable variation. Trial 1 recorded the highest loss at 38.39%, while Trial 2 showed the lowest at 31.76%, followed by Trial 3 with a loss of 32.68%. The computed average loss of 34.28%, represented by the horizontal line, indicates that roughly one-third of the input material was not recovered as grated output.

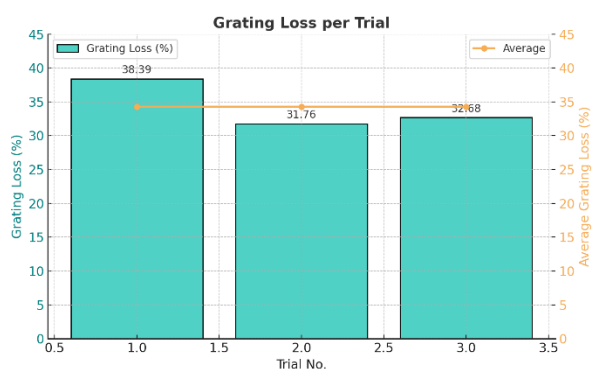


Fig. 11. Grating loss per trial of the developed coconut grating machine

The variability in loss across trials suggests minor inconsistencies in the grating process, possibly due to differences in coconut characteristics or operational handling. The results highlight the need for design refinements, particularly in the cutting blade configuration and feed mechanism, to enhance grating performance and minimize material waste.

3.5 Performance Comparison of the Semi-Automated Coconut Grater (SACG) and the Semi-Automated Coconut Grater Integrated with System (SACGIS)

Figure 12 presents the comparative performance of the Semi-Automated Coconut Grater (SACG), an existing machine commonly used in public markets where the operator must manually hold the coconut during grating, and the Semi-Automated Coconut Grater Integrated with System (SACGIS), the fabricated machine developed in this study. The comparison includes operating time, grating output, power consumption, total energy used, and specific energy consumption. The SACG completed the grating process in 0.28 hours, processing 7.32 kg of coconut meat, whereas SACGIS required 0.63 hours to process 4.19 kg.

However, SACGIS exhibited greater energy efficiency, consuming only 0.0257 kW of power and 0.016 kWh of energy, which is significantly lower than SACG's 1.1185 kW and 0.3184 kWh. Its specific energy consumption of 0.0039 kWh/kg was about 11 times lower than SACG's 0.043 kWh/kg, indicating significantly improved energy performance.

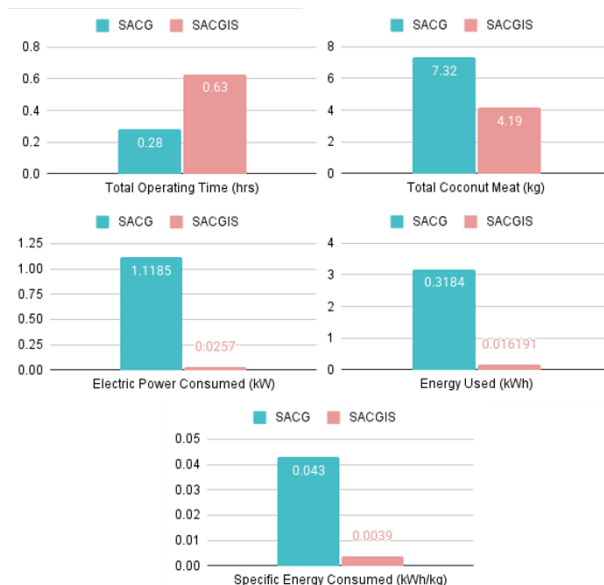


Fig. 12. Comparative performance of the Semi-Automated Coconut Grater (SACG) and the Semi-Automated Coconut Grater Integrated with System (SACGIS)

Overall, while SACG provides faster throughput and higher output, it operates with greater energy demand and safety risk. In contrast, SACGIS ensures safer operation, improved energy efficiency, and cost-effectiveness—making it more sustainable for small- to medium-scale coconut processing applications.

4. CONCLUSION

The researchers' development of a semi-automated coconut meat grater marks a key advancement in coconut processing technology. The machine demonstrated efficient performance with a processing rate of 4.60 kg/h, reducing manual effort and enhancing safety through hands-free loading. Its spring-loaded blade mechanism improved reliability, though enhancements to the blade and coconut holder are needed to shorten the current loading time of 40 seconds to one minute.

The use of an Arduino-controlled stepper motor ensured stable rotational speed and uniform output. The machine achieved an average grating efficiency of 69.21% and a recovery of 65.72%, indicating effective energy use and minimal waste. However, regression and correlation analyses were inconclusive due to limited data per trial; a more detailed dataset could yield stronger insights. Motor speed was limited to 150 RPM to preserve the holder's structure, balancing efficiency with system longevity. While the adjustable blade design offers flexibility, the variability in coconut size challenges full utilization, suggesting a need for a more adaptable blade system. Overall, the design shows promise, with opportunities for further refinement to maximize efficiency and usability.

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