

## **Design and performance analysis of a stick making machine to support the sustainability of palm oil leaf waste**

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### **Abstract**

The palm oil industry is a key sector in Indonesia, yet it produces significant amounts of leaf waste, which has been underutilized and has the potential to pollute the environment. The fundamental problem currently lies in the largely manual process of utilizing leaf waste, making it inefficient for large-scale production. This research aims to design a machine for making palm leaf stick-making from palm leaf waste to support sustainability principles. The method used is Reverse Engineering to analyze and improve the existing machine design, with a focus on the function, capacity, and safety aspects. This data collection was done through field surveys and Focus Group Discussions (FGD). The expected result of this research is a more efficient palm leaf and frond separating machine design, with a target performance of 1.5 kg per 10 minutes (9 kg/hour). The design's advantage lies in the ease of maintenance, especially in removing and replacing shaft and chopping blade components. This research can answer the needs of industry and society for environmentally friendly appropriate technology, thus supporting sustainable waste management. The palm oil industry is a cornerstone of Indonesia's economy, yet it generates substantial amounts of leaf waste that remain largely underutilized, presenting a significant environmental management challenge. The fundamental problem lies in the reliance on manual processing methods, which are inefficient and unsuitable for large-scale waste valorization. This study aimed to design and analyze a stick machine to process palm oil leaf waste, thereby supporting sustainability principles and circular economy initiatives. The research methodology applied was Reverse Engineering, which was used to systematically evaluate and improve upon an existing machine design, with specific attention to enhancing function, operational capacity, and safety. Data collection was conducted through comprehensive field surveys and Focus Group Discussions (FGD) with stakeholders to ensure the design met practical needs. The resulting prototype, powered by a 3 HP electric motor, demonstrated a calculated processing capacity of 9 kg per hour (equivalent to 1.5 kg per 10 minutes). Structural analysis confirmed the machine's robustness, with a calculated shaft safety factor of 3.48, ensuring reliability under operational loads. The design prioritizes ease of maintenance, featuring a mechanism that simplifies the removal and replacement of the shaft and chopping blade components. Furthermore, the machine's operation is environmentally friendly, contributing to waste reduction. In conclusion, this research successfully developed a feasible, efficient, and sustainable technical solution for managing palm oil leaf waste, offering a valuable appropriate technology for both industry and local communities.

Keywords: Palm leaf lids; palm leaf waste; design; recycle; sustainability

### **1. Introduction**

The palm oil industry is a strategic sector that makes a significant contribution to the Indonesian economy, particularly in the plantation sector [1], [2], [3]. However, this industry's success presents environmental challenges, primarily through the generation of substantial palm leaf waste that remains



largely underutilized [4]. The palm oil industry is a strategic sector that makes a significant contribution to the Indonesian economy, particularly in the plantation sector [1], [2], [3]. However, the success of the palm oil industry also presents new challenges. One challenge is the large amount of palm leaf waste that remains underutilized [4]. Much of this palm leaf waste is simply left to rot, leading to environmental pollution. A one-hectare palm oil plantation with approximately 130 trees produces a significant amount of biomass waste [5]. Each tree produces approximately 22 fronds per year, with a total weight of 9 tons of fresh fronds (equivalent to 0.66 tons of dry matter) per hectare. This palm oil waste, particularly the palm leaf frond waste, has significant potential for improving people's livelihoods if further processed [6].

This initiative aligns with efforts to reduce waste and the environmental impact of the palm oil industry [7]. One innovation is utilizing palm leaf midribs to create added value, such as palm fronds. Currently, the process of producing palm fronds is still carried out manually, which is time-consuming and inefficient for large-scale production [8]. This is the formulation of the problem in this study. Furthermore, we need to know that Indonesia is one of the main producers with great potential to export palm fronds to countries with high market potential. The manual production of palm fronds remains prevalent in palm oil-growing communities. The process of making palm fronds manually is still widely practiced by communities in palm oil-producing areas. This traditional method is time-consuming, requires a lot of energy, and produces inconsistent results. Furthermore, the process of peeling and shredding palm frond veins manually often causes fatigue in workers and low productivity. These problems indicate the need for innovation in the form of a palm frond shredding machine that can improve work efficiency and production quality. Through the design of the right palm frond shredding machine, it is hoped that the process of processing palm fronds into palm fronds can be done more quickly, efficiently, and produce uniform sizes [9]. In addition, the use of this machine can open new business opportunities for communities around palm oil plantations, increase the added value of agricultural waste, and support efforts to develop small and medium-sized industries based on local resources. Thus, the design of a palm leaf shredding machine is not only a technical solution to increase productivity, but also plays an important role in supporting the circular economy and sustainable development in the agricultural sector [10].

Based on previous research [11], that the palm oil palm frond shredder machine using an electric motor with a capacity of 1800 fronds/hour is still not able to increase waste processing productivity by 85%. Another study developed a separator machine using a roll-pulling mechanism with a capacity of 7 kg/hour (approximately 0.11 kg/minute), which was also considered suboptimal [12]. The novelty of this research lies in designing an improved palm frond separator machine that emphasizes enhanced maintainability, specifically through the ease of disassembling the leaf-chopping shaft for cleaning and replacing worn chopper components. This design aims to significantly increase productivity in palm leaf waste recycling, ultimately supporting circular economy principles and sustainable development in the agricultural sector [10]. Based on the results of research 2 [12], that the manufacture of a machine as a separator between palm oil fronds and leaves uses a roll as a puller with a capacity of 7 kg/hour, meaning that in one minute it can produce 0.11 kg. Both studies stated that the results are still not effective and optimal. For this reason, the novelty of this research will design a palm oil frond separator machine with the advantages of the design offered providing ease of maintenance, namely the ease of removing the leaf chopper shaft part for cleaning and replacing the chopper component if the function has begun to decline. The design offered can also increase productivity in the recycling process of palm leaf waste. The purpose of this research is to utilize palm leaf waste as the main material for making fronds by designing an efficient frond making machine that emphasizes the design of the machine on function, capacity and safety.

## 2. Methods

This study employed a research and development approach to create a palm frond processing machine, focusing on functionality, structural strength, cost-effectiveness, and operational safety [13], [14]. The problem-solving strategy was developed from survey findings and data collection,

emphasizing the development of a machine concept that prioritizes ease of maintenance and component replacement. This research integrates technology into the waste recycling process to address both industrial and community needs.

The methodological approach centered on Reverse Engineering, which involved systematically dismantling and analyzing existing machine designs to identify improvements [15], [16], [17]. This process was specifically applied to mechanical components to enhance functionality, capacity, and safety. Data collection incorporated two primary techniques: direct observation of current palm leaf waste processing methods to identify operational challenges, and Focus Group Discussions (FGD) with stakeholders to gather technical requirements and practical insights for machine design.

Palm oil waste management requires practical steps to ensure sustainability. The goal is to avoid environmental pollution and produce a product with economic value [13], [14]. Problem-solving strategies are designed based on findings from surveys and data collection, including developing a machine concept that addresses ease of overhaul and component replacement, mechanical design, and research machine design that focuses on sustainability. This research will integrate technology into the waste recycling process to meet the needs of industry and society. The problem-solving approach used is reverse engineering, a process that involves dismantling a product to study its operation and can also be used to improve or redesign it [15], [16], [17]. This process can be applied to various products, including software, mechanical components, and structures. Designs derived from previous research will serve as a reference source for increasing capacity [18].

This research is fundamental research focused on designing a palm leaf stick making machine, considering aspects of function, strength, cost, and safety. This study employed two data collection techniques: observation to assess the actual conditions of the palm leaf waste processing process, thus identifying the need for designing an integrated machine, and focus group discussions to discuss the design and implementation of the machine [19], [20], [21].

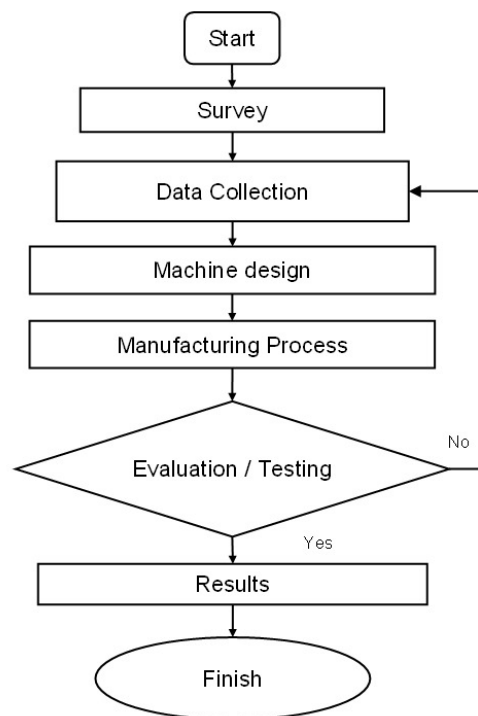


Figure 1. Research flow

- a. Survey–Identifying immediate problems in the field and reviewing relevant literature.
- b. Data Collection–Discussions with stakeholders (experts, users) to gather design requirements for a palm leaf shredding machine.



shredding/separating system. The overall dimensions of the machine are 850 mm (L) x 540 mm (W) x 1140 mm (H). The resulting machine consists of several main components, as shown in Figure 3.

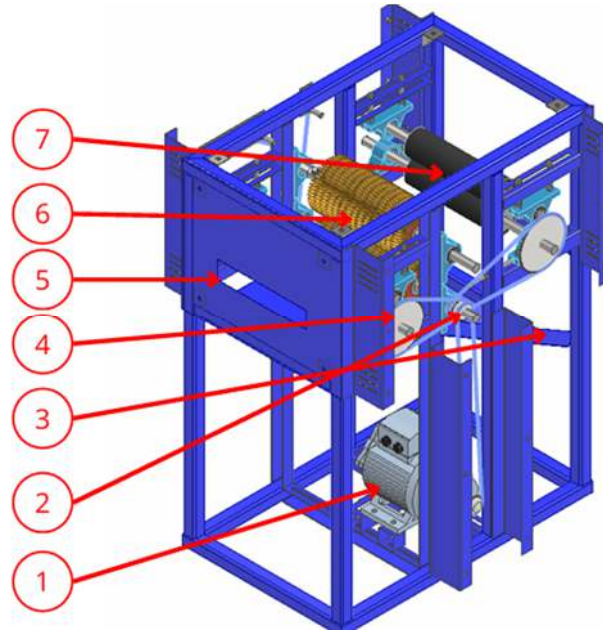


Figure 3. Oil Palm Leaf Shredding Machine Parts

1. Single-Phase Electric Motor: Driving force.
2. Chain & Sprocket: Power transmission system.
3. Slider: Palm leaf stalk outlet.
4. Front Rubber Roller: Rubber-coated roller that automatically pulls palm leaves into the machine.
5. Feed Inlet: Channel or inlet through which palm leaves are fed into the machine.
6. Wire Brush: Rotating wire brush that scrapes or shreds the leaf flesh, leaving only the stalks.
7. Rear Rubber Roller: Rubber roller that helps pull the leaves out after the shredding process is complete.

The shredding process takes place systematically through the following stages:

- a. Raw Material Preparation: The palm leaf waste to be processed first undergoes a sorting and cleaning process to remove foreign materials or other impurities.
- b. Feeding Process (Material Input): The dried palm leaves are fed into the machine through an inlet designed for operator convenience. This process is a crucial initial step to ensure a smooth flow of material into the processing unit.
- c. Automatic Pulling: After entering, the oil palm leaves are pulled into the processing chamber by the front rubber roller. This roller acts like the "hand" of the machine, actively pulling the leaves into the system's core in a stable and continuous manner, preventing clogging and ensuring a smooth process.
- d. Shredding: The pulled leaves then enter the main working area, the Wire Wheel Brush. This wire brush rotates synchronously at high speed, using friction and tensile forces to scrape or shred the flesh of the leaves, leaving only the leaf veins (stalks).
- e. Material Discharge: After the shredding process is complete, the processed material—clean stalks and shredded leaf fiber (biomass)—is pulled out of the processing chamber by the rear rubber roller. This roller ensures that all material exits the machine smoothly, without being left behind or clogging.

- f. Output: The material exiting the machine consists of two types: clean stick stems, ready to be used as raw materials for handicrafts, and chopped biomass, which can be used as organic fertilizer or alternative fuel.

Thus, this machine not only reduces waste but also creates two economically valuable products, in line with the concepts of sustainability and the circular economy described in journals related to waste recycling. Based on design and performance calculations, the following results were obtained:

- a. Machine Performance and Capacity: Based on the calculation analysis, this machine is designed to have an output capacity of approximately 5 kg/hour. This performance target demonstrates the machine's feasibility for small-to-medium-scale operations. Compared with previous findings, such as a separator with a capacity of 7 kg/hour and a shredder with a capacity of 1,800 sticks/hour, which were deemed suboptimal, this design offers a more scalable and reliable solution. This capacity is achieved through a precisely calculated leaf pulling system.
- b. Power and Transmission Analysis: Motor power calculations indicate that using a 3 HP single-phase motor (2.2 kW, 1430 rpm) provides a substantial power reserve for the system. The actual processing power requirement for leaf pulling and separation is only 956.9 W, allowing the motor to operate under mild conditions with a high safety factor against overloading. Power transmission utilizes an RS40 chain (12.7 mm pitch) with a 20T:60T sprocket ratio, resulting in a reduction in rotational speed from 1430 rpm at the motor to 476.7 rpm at the main shaft. The chain's linear speed of 6.05 m/s and chain tensile force of 363.4 N are considered adequate for effective leaf pulling.
- c. Component Strength and Safety Factor: Strength analysis of the main shaft (25 mm diameter, S45C material) was performed based on the maximum transmitted torque. The torque at the 60T sprocket is 44.08 Nm, resulting in a shear stress of 14.37 MPa. This value is well below the material's allowable shear stress (50 MPa), providing a safety factor of 3.48. This ensures the shaft's reliability in withstanding operational and shock loads.

### 3.1 Machine design and working mechanism

The palm frond processing machine design has been successfully developed through systematic stages of needs identification, design implementation, and prototype fabrication. The final design, illustrated in Figure 2, incorporates a 3 HP single-phase electric motor, chain and sprocket transmission system, rubber rollers for automatic leaf feeding, and a wire brush as the core shredding component. The machine's compact dimensions (850 mm × 540 mm × 1140 mm) make it suitable for small to medium-scale operations in palm oil communities.

The operational process begins with raw material preparation, where palm leaves are sorted and cleaned. The feeding mechanism utilizes front rubber rollers that automatically pull leaves into the processing chamber. The central shredding unit, comprising rotating wire brushes, effectively separates the leaf flesh from the veins through friction and tensile forces. Finally, the rear rubber rollers discharge the processed materials—clean stalks for handicraft applications and shredded biomass for organic fertilizer or alternative fuel.

### 3.2 Performance analysis and technical specifications

Technical calculations demonstrate that the machine achieves a production capacity of 9 kg/hour (equivalent to 1.5 kg/10 minutes), representing a significant improvement over previous designs. The power transmission system, utilizing RS40 chain with 20T:60T sprocket ratio, reduces rotational speed from 1430 rpm at the motor to 476.7 rpm at the main shaft. The chain's linear speed of 6.05 m/s and tensile force of 363.4 N provide sufficient power for effective leaf processing.

Structural analysis confirms the machine's robustness, with the main shaft (25 mm diameter, S45C material) exhibiting a shear stress of 14.37 MPa well below the material's allowable stress of 50 MPa. The calculated safety factor of 3.48 ensures reliable operation under various loading conditions, including potential shock loads during processing.

### 3.3 Comparative advantage and maintenance features

The design addresses key limitations of previous machines through enhanced maintainability. The modular construction allows easy access to the shaft and wire brush components, facilitating quick cleaning and replacement. This feature significantly reduces downtime and maintenance costs compared to conventional designs. The machine's efficiency in processing palm fronds not only improves productivity but also ensures consistent output quality, addressing the inconsistency issues associated with manual processing methods.

#### Research contributions

This research provides significant contributions across technical, scientific, and practical dimensions in palm oil waste processing. Technically, the study delivers a functional design and prototype of a palm oil frond separating machine that specifically addresses the limitations of previous suboptimal designs. From a sustainability perspective, the machine embodies circular economy principles by transforming previously discarded palm frond waste into economically valuable products. Consequently, this research not only mitigates environmental impact but also generates new economic opportunities for local communities, while advancing scientific knowledge in sustainable waste management technology. This research provides several key contributions, both technically, scientifically, and practically, in the context of palm oil waste processing.

**Technical Contribution (Prototype):** The primary contribution is the development of a functional design and prototype for a palm oil frond separating machine. This design specifically addresses the weaknesses of the existing machine, which was deemed suboptimal.

**Contribution to Sustainability:** This machine supports the principles of a circular economy by converting palm frond waste, which has previously been discarded, into palm frond products with economic value. Thus, this research not only reduces environmental impact but also creates economic opportunities for the community.

#### Managerial implications

The results of this machine design have several direct managerial implications for stakeholders in the palm oil industry, such as plantation managers, cooperatives, or palm frond craft SMEs.

**For the Palm Oil Industry:** Plantation companies can integrate this machine into their waste management systems as part of their environmental responsibility (corporate sustainability) while simultaneously creating new revenue streams from waste.

**For the Government and Related Institutions:** The government can support the downstreaming of this research through MSME mentoring programs and incentives for industries implementing environmentally friendly technologies. Furthermore, research institutions such as Astra Polytechnic can use this machine as a model for the development of other recycling technologies.

The outcomes of this machine design carry substantial managerial implications for various stakeholders within the palm oil sector, including plantation managers, cooperatives, and SMEs involved in palm frond crafts. For the palm oil industry, plantation companies can strategically incorporate this technology into their waste management systems, thereby fulfilling corporate sustainability responsibilities while simultaneously generating new revenue streams from what was previously considered waste. From a policy perspective, governmental and related institutions can facilitate the adoption of this innovation through targeted support for MSMEs and by providing incentives for industries that implement eco-friendly technologies. Furthermore, academic institutions such as Astra Polytechnic can leverage this machine as a foundational model to spur the development

of subsequent recycling technologies, thereby extending the research impact beyond its immediate application.

#### 4. Conclusion

Based on the design and technical calculations, this palm leaf stick-making machine has been successfully designed. Technical calculations indicate that the machine uses a 3 HP (2.2 kW) motor capable of producing up to 44.08 Nm of torque on the main sprocket, with a shaft safety factor of 3.48, indicating a safe and reliable mechanical structure. The target production capacity of 9 kg/hour (1.5 kg/10 minutes) has been mathematically calculated and is believed to be achievable, representing a significant improvement over previous machines. The main advantage of this design is ease of maintenance, as components such as the shaft and wire brush can be easily removed for cleaning or replacement. Furthermore, the machine is designed to be an economical and environmentally friendly solution, utilizing recycled materials and efficient fabrication technologies such as laser cutting. Thus, this machine functions not only as an industrial tool but also as an innovative solution that supports the principles of sustainability and a circular economy in palm leaf waste management, while also opening up new economic opportunities for communities surrounding palm oil plantations. This study successfully designed a palm leaf stick-making machine that effectively supports the sustainability of palm oil leaf waste management. The technical design, powered by a 3 HP (2.2 kW) motor, achieves a calculated torque of 44.08 Nm on the main sprocket with a shaft safety factor of 3.48, confirming the mechanical structure's reliability. With a mathematically calculated production capacity of 9 kg/hour (1.5 kg/10 minutes), the machine demonstrates significant improvement over previous designs. The design's primary advantage lies in its maintenance-friendly features, particularly the easy removal and replacement of shaft and wire brush components. Furthermore, the implementation of economical fabrication technologies and recycled materials enhances its environmental compatibility. This research ultimately presents an innovative solution that not only functions as an industrial tool but also promotes circular economy principles by creating economic opportunities for communities surrounding palm oil plantations through sustainable waste valorization.

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