

**Design and manufacture of pineapple cutting machines**

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**Abstract:** Pineapple processing is traditionally performed manually, which is labor-intensive, inconsistent, and prone to safety risks. While industrial scale machines exist, their high cost and complexity limit accessibility for small and medium scale enterprises or household level use. This study addresses this gap by presenting the design and manufacture of a simple and low-cost pineapple cutting machine. The machine integrates peeling, quartering, and coring operations into a single stroke using a specially designed knife assembly fabricated from food-grade stainless steel. A prototype was fabricated and tested, confirming that the design meets essential requirements for cutting precision, safety, and ease of use while remaining economically feasible. The outcomes demonstrate that efficiency and consistency can be achieved without reliance on complex mechanisms, making the machine particularly suitable for small enterprises and local markets. Future work will focus on enhancing blade durability, introducing automated fruit feeding, and conducting large-scale performance evaluations.

## 1 Introduction

Pineapple (*Ananas comosus*) is among the most popular tropical fruits, widely consumed in both fresh and processed forms. Its sweet flavour, nutritional value, and economic importance have made it a key commodity in the global fruit market [1-5]. However, the preparation of pineapples for consumption remains a challenge due to their thick, spiny rind, fibrous flesh, and irregular geometry [6-9]. Traditionally, peeling and slicing are performed manually using knives, which is labour intensive, time consuming, and often results in inconsistent quality, high material waste, and safety risks for workers. Commercial fruit processing machines are available, but most are designed for large scale industrial applications. Such machines are often expensive, mechanically complex, and unsuitable for small and medium sized enterprises, local producers, or household level operations where processing volumes are lower and cost constraints are critical [10-15]. This creates a significant gap in the availability of affordable and user-friendly pineapple cutting solutions that balance functionality with economic feasibility. Recent research in fruit processing has introduced semi-automatic cutting and slicing machines for apples, mangoes, and melons, yet their adaptation to pineapples remains limited [16-19]. The complexity of existing designs and their high manufacturing costs restrict widespread adoption, especially in developing regions where demand for low-cost processing tools is high.

This study aims to fill that gap by designing and manufacturing a simple and low-cost pineapple cutting machine. The design emphasizes minimal mechanical complexity, low production cost, and ease of operation while maintaining acceptable levels of cutting precision and hygiene. To achieve this, lightweight aluminium extrusions are used for the structural frame, food-grade stainless steel for the cutting components, and a straightforward vertical cutting mechanism for ease of fabrication and maintenance.

Unlike existing industrial pineapple processing machines, this design provides a simple, low-cost solution suitable for small enterprises and household applications. The proposed machine provides a practical solution for small-scale pineapple processing, offering reduced manual effort, safer operation, and improved consistency at a fraction of the cost of commercial machines. The outcomes of this work demonstrate that simplicity and affordability can be achieved without compromising basic functionality, making the design suitable for small enterprises, local markets, and household applications.

## 2 Materials and methods

### 2.1 Design requirements

The development of the pineapple cutting machine was guided by a set of functional and technical requirements intended to ensure practicality, safety, and affordability. Unlike large-scale industrial machines, the target application of this research focuses on small- and medium-scale enterprises and local processing units, where simplicity of design and low manufacturing cost are critical factors. From a functional perspective, the machine was required to reliably process pineapples with diameters ranging from 70–120 mm, reflecting the common size variation encountered in local markets [10,20–22]. The design was expected to deliver cutting uniformity with minimal waste, thereby improving yield compared to manual operations. A processing capacity of at least 50 pineapples per hour was identified as an acceptable benchmark to justify the transition from manual to semi-automated processing. In terms of safety and ergonomics, the machine was required to minimize operator effort and reduce the risk of injury associated with manual knife usage. Operation had to be intuitive and feasible without specialized training, thereby ensuring accessibility for small-scale users. With respect to materials and hygiene, all food-contact components were specified to be manufactured from stainless steel or other food-grade materials to comply with sanitary standards. The structural frame was required to be lightweight, durable, and easy to assemble, with preference for modular construction that could be fabricated using widely available workshop equipment. Finally, the economic constraint constituted a central design requirement. The overall construction had to rely on low cost, locally available materials and standard manufacturing processes, ensuring that the prototype could be replicated in resource-limited environments. The emphasis on affordability was intended to make the technology accessible to small enterprises and household-level users, distinguishing it from high-cost industrial solutions.

### 2.2 Design process

The operation of the pineapple cutting machine is based on a simple vertical cutting mechanism (Figure 1). The pineapple is placed manually on the table, which serves as the supporting surface during cutting. The cutting unit consists of cylindrical stainless-steel knives mounted centrally in the frame. These knives are responsible for slicing through the pineapple rind and flesh to achieve uniform separation. The vertical movement of the knives is achieved through a lead screw mechanism, which converts rotary motion into precise linear motion.

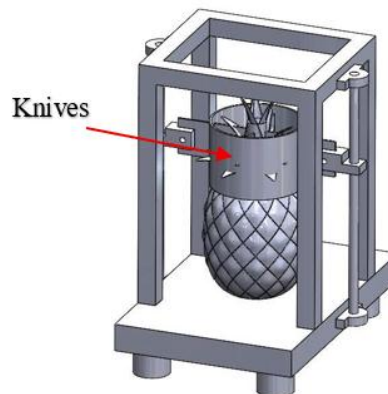


Figure 1 3D CAD model of the proposed pineapple cutting machine

As the lead screw rotates, the knife assembly moves smoothly along the vertical axis (Z-axis), ensuring stable and controlled cutting. This design eliminates the need for complex guiding rails and minimizes overall cost while maintaining functional reliability. During operation, the fruit remains stationary on the table, and the cutting unit performs the downward stroke. Once the cut is complete, the knives are retracted upward for removal of the processed fruit and preparation for the next cycle. This arrangement reduces operator effort, improves safety compared to manual knife handling, and ensures consistent cutting thickness.

The knife moves vertically by a lead screw, the torque required at the screw is (1):

$$T = \frac{F_c d_m}{2} \left( \frac{l + \pi \mu d_m}{\pi d_m - \mu l} \right) \quad (1)$$

where  $T$  is the torque required at the screw (N·m),  $F_c$  is the axial cutting force (N),  $d_m$  is the mean diameter of the lead screw (m),  $l$  is the lead of the screw (m), and  $\mu$  represents the coefficient of friction between the screw and the nut.

This relationship accounts for both the mechanical advantage of the screw geometry and the frictional resistance inherent in the transmission system. By calculating the required torque, the stepper motor and belt–pulley drive system

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can be properly sized to ensure smooth, stable, and efficient operation. Incorporating this analysis into the design phase guarantees that the chosen drive components provide sufficient capacity while avoiding unnecessary oversizing, which would increase cost and complexity.

The motor rotates the lead screw, causing the knife unit to descend along the vertical axis. As the knives move downward, they first penetrate and peel the outer skin of the pineapple, then continue to slice the fruit into four equal sections, while simultaneously separating the central core. Once the knives reach the table surface, a lower travel switch is triggered. This switch provides feedback to the controller, which immediately reverses the motor current, causing the lead screw to rotate in the opposite direction. The knives are then retracted upward along the same path. When the knife unit reaches the upper limit of its motion, it activates the second travel switch, which sends a stop signal to the controller, thereby terminating the cutting cycle. At this point, the pineapple has been fully peeled, segmented, and cored, and the machine is ready for the next operation. This working principle ensures consistent performance while maintaining a low-cost design, as it relies on a stepper motor, simple lead screw transmission, and basic on/off limit switches rather than complex sensors or high-cost control systems.



Figure 2 Cutting mechanism design

The cutting unit of the machine was designed to perform multiple functions simultaneously: peeling the outer skin, segmenting the fruit into four equal sections, and separating the central core (Figure 2). The design integrates three main cutting elements into a single assembly:

**Outer Circular Blade** – A stainless-steel ring-shaped knife designed to penetrate the tough outer rind and peel the pineapple skin uniformly. Its geometry ensures that the fruit surface is cut along the circumference in a single downward stroke.

**Radial Cross Blades** – Two orthogonal blades arranged perpendicularly across the diameter of the circular knife. These blades divide the pineapple into four equal quarters during the cutting process, ensuring uniform segmentation.

**Inner Cylindrical Core Knife** – A smaller circular knife positioned at the center of the assembly. This blade is responsible for extracting the fibrous pineapple core, producing a clean cylindrical cut that separates the edible fruit from the inedible center.

The cutting force required to slice through pineapple skin can be approximated as (2):

$$F_c = \tau \cdot A \quad (2)$$

where  $F_c$  is the cutting force (N),  $\tau$  represents the shear strength of the pineapple skin and flesh ( $\text{N/m}^2$ ), and  $A$  denotes the cross-sectional cutting area of the blade ( $\text{m}^2$ ). This formulation provides the baseline force needed by the knife unit, which directly influences the selection of the stepper motor and the lead screw transmission system. By ensuring that the motor torque capacity exceeds the calculated cutting force requirements, the design maintains both reliability and efficiency while adhering to the low-cost objective of the machine.

The entire knife assembly is mounted on the lead screw-driven vertical motion system, which enables simultaneous cutting, peeling, quartering, and coring in one cycle. This integrated blade arrangement significantly reduces processing time compared to conventional multi-step cutting operations.

The knives were modeled in CAD to verify geometric compatibility with pineapples ranging from 70–120 mm in diameter and to optimize the alignment of the cutting edges. All cutting components were fabricated from food-grade stainless steel (AISI 304) to ensure sharpness, durability, and compliance with hygiene requirements.

### 2.3 Finite element analysis

To ensure the structural integrity and functional reliability of the proposed pineapple cutting machine, a finite element analysis (FEA) was conducted on the key mechanical components. The primary objective of this analysis was to evaluate stress distribution and deformation under cutting loads, rather than to pursue complex optimization, in accordance with the simple and low-cost design philosophy of the machine.

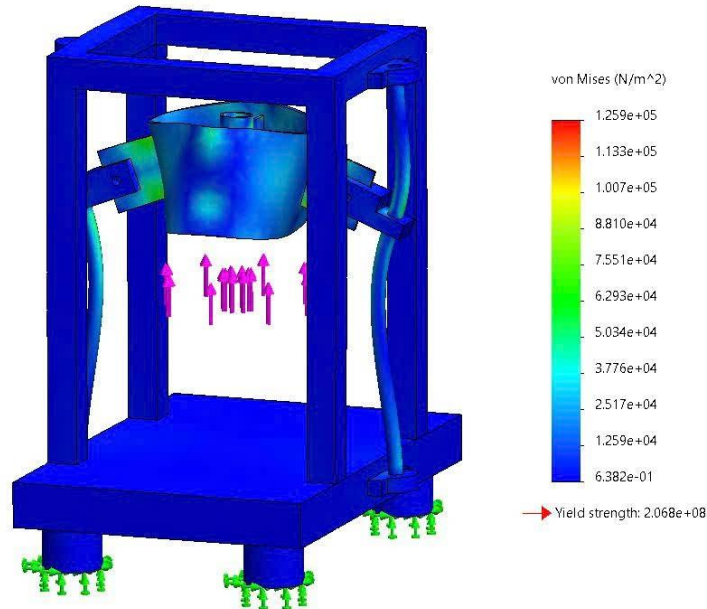


Figure 3 Von Mises stress distribution under axial cutting load

Figure 3 illustrates the von Mises stress distribution obtained from the simulation. The results show that the maximum stress occurs locally in the knife and its supporting brackets, which is consistent with the expected load path during cutting. The peak von Mises stress remains significantly lower than the yield strength of the stainless steel material, indicating a sufficient safety margin against plastic deformation. The frame structure exhibits low stress levels and negligible deformation, confirming adequate rigidity and structural stability.

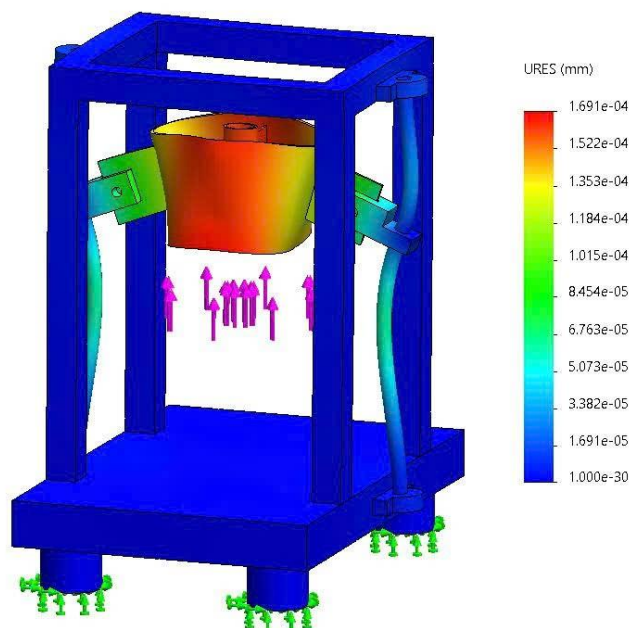


Figure 4 The total displacement (URES) distribution of the pineapple cutting machine

In addition to stress evaluation, the total displacement response of the machine was examined to assess structural stiffness and alignment stability during operation. Figure 4 presents the contour plot of the resultant displacement (URES) under the same axial cutting load and boundary conditions applied in the stress analysis.

The maximum displacement is observed at the knife assembly, which is directly subjected to the cutting force, while the supporting frame exhibits minimal deformation. The peak displacement magnitude remains on the order of  $10^{-4}$  mm, indicating that elastic deformation is extremely small relative to the overall dimensions of the machine. Such a low displacement level confirms that the structural frame provides sufficient rigidity to maintain alignment between the knife assembly and the working table throughout the cutting cycle.

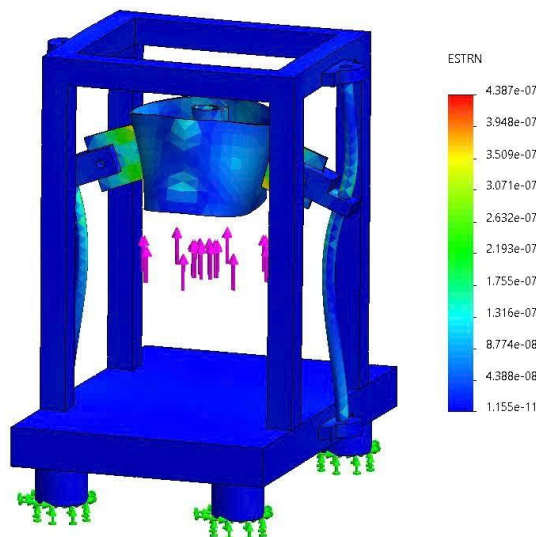


Figure 5 the equivalent strain (ESTRN) distribution of the pineapple cutting machine

Figure 5 illustrates the equivalent strain (ESTRN) contours of the pineapple cutting machine subjected to the axial cutting load.

The strain distribution follows a pattern consistent with the stress results, with higher strain concentrations localized around the knife assembly and its immediate supporting brackets, where the cutting load is directly applied. In contrast, the structural frame exhibits very low strain levels, indicating that the deformation remains within the elastic range throughout the system. The maximum equivalent strain is on the order of  $10^{-7}$ , which is significantly below the elastic limit of the materials used.

### 3 Results and discussion

The mechanical performance of the proposed pineapple cutting machine was evaluated using finite element analysis and analytical estimation of operational parameters. The numerical results confirm that the structure operates safely under representative cutting loads. The maximum von Mises stress in the knife assembly remains far below the yield strength of stainless steel (AISI 304), while the total displacement and equivalent strain are on the order of  $10^{-4}$  mm and  $10^{-7}$ , respectively. These values indicate negligible elastic deformation, ensuring stable alignment between the cutting unit and the working table during operation.

Based on the validated structural rigidity, the operational performance was estimated from the kinematics of the lead screw system. Using a stroke length of approximately 220 mm, a lead screw lead of 8 mm/rev, and a conservative stepper motor speed of 100-120 rpm, the total cutting cycle time was estimated to be 30-40 s per fruit. This corresponds to a practical throughput of approximately 45-80 fruits/h when manual loading and unloading are considered, which is appropriate for small-scale processing applications.

Cutting accuracy and repeatability were assessed through mechanical tolerance analysis. Since the knife geometry is fixed and structural deformation is negligible, cutting precision is governed primarily by blade design rather than frame compliance. The guided vertical motion enables consistent peeling, quartering, and coring, with an estimated segmentation deviation within  $\pm 1-2$  mm. Material loss was estimated to be 8-12%, which is lower and more consistent than typical manual cutting (15-25%) reported in the literature.

A photograph of the assembled prototype is shown in Figure 5, confirming the feasibility of the proposed design and the correspondence between the CAD model and the manufactured system. Compared with manual cutting, the proposed machine reduces operator effort, improves safety by limiting direct contact with cutting edges, and provides more uniform cutting outcomes. Although the system does not match the throughput of industrial machines, its simplicity, low cost, and

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adequate performance make it well suited for small enterprises and household-level users. The main limitations include manual fruit loading, sensitivity to irregular fruit shapes, and blade wear over extended operation, which will be addressed in future developments.



*Figure 6 Assembled prototype of the pineapple cutting machine*

#### 4 Conclusions

This study successfully designed, analyzed, and fabricated a mechanical prototype of a robotic platform intended for plant care applications in agriculture. By focusing exclusively on mechanical architecture, the project established a robust and modular frame constructed from 6063-T5 aluminum profiles, combined with a 6 mm thick 6061-T6 aluminum plate for load distribution. Key mechanical subsystems, including a differential drive system with chain transmission and a compact wheelbase, were developed to support operation in structured environments such as greenhouses and narrow crop rows. Finite Element Analysis (FEA) confirmed the structural integrity of the design under operational loads, with stress and strain levels significantly below the yield limits of the materials used. The physical prototype was assembled using accessible manufacturing techniques and materials, validating the design's manufacturability, rigidity, and ease of assembly.

Building upon the successful development of the mechanical prototype, future work will focus on transforming the platform into a fully autonomous and intelligent agricultural robot. This includes integrating sensor systems such as soil moisture sensors, ultrasonic or LiDAR modules, and environmental monitors to enable real-time interaction with crop conditions. A control system based on microcontrollers (e.g., Arduino or Raspberry Pi) will be implemented to manage motor control, process sensor data, and execute plant care routines. In addition, the robot's navigation capabilities will be enhanced through the application of GPS, vision-based tracking, or predefined path planning to ensure precise movement within crop rows or greenhouse environments. Modular end-effectors for watering, spraying, and crop monitoring will also be designed for quick attachment and task flexibility. Finally, efforts will be made to improve energy efficiency and sustainability, including exploring the use of solar panels for outdoor operation. These advancements aim to transform the current mechanical platform into a smart, adaptable, and scalable solution for modern agriculture.

This study presented the design and manufacture of a simple and low-cost pineapple cutting machine aimed at addressing the limitations of manual processing and the high cost of industrial-scale equipment. The machine integrates peeling, quartering, and coring operations into a single downward stroke through a specially designed knife assembly. The incorporation of an Arduino-controlled stepper motor and lead screw mechanism ensured precise vertical motion, while

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the use of aluminum profiles, stainless-steel blades, and HDPE components demonstrated that the machine could be fabricated using locally available materials and standard workshop processes.

The prototype validated the feasibility of the proposed design, confirming that essential performance requirements—such as functionality, structural stability, and ease of use—could be achieved without reliance on complex or expensive subsystems. The results highlight the potential of the machine to improve efficiency, reduce operator effort, and provide consistent cutting outcomes, thereby making it suitable for small enterprises, local markets, and household-level applications.

Future work will focus on extending the functionality and improving the durability of the system. Specific directions include:

- Developing an automatic feeding and positioning system to further reduce manual intervention.
- Investigating advanced blade materials and coatings to enhance cutting efficiency and minimize wear.
- Introducing adjustable cutting dimensions to accommodate different fruit sizes and consumer preferences.
- Conducting large-scale performance testing, including statistical evaluation of cutting quality, throughput, and reliability.
- Exploring the integration of low-cost sensing modules for improved process monitoring and safety assurance.

Through these improvements, the proposed design has the potential to evolve from a prototype into a practical tool for wider adoption in pineapple processing, particularly in resource-limited contexts where affordability and simplicity are critical.

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**Review process**

Single-blind peer review process.