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Research Article

Development of a prototype pineapple peeling machine

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Abstract
This article presents a complete process from design to fabrication for a prototype pineapple peeling machine. The primary objective of the machine is to enhance productivity and improve product quality while simultaneously reducing time and cost. Firstly, the physical and mechanical properties of pineapples were investigated, with a special focus on their dimensions and the forces necessary for peeling. The proposed prototype is equipped with a core punch mechanism, which has been developed through the utilization of calculations and design techniques enthusing Siemen's NX (also known as NX Unigraphics, or UG) software. Based on the three-dimensional (3D) design, a prototype for a pineapple peeler was developed and fabricated. The experimental results show that the proposed design succeeded in peeling a pineapple within 2 seconds. Lastly, the production cost is only 726 USD. Compared to existing products available on the market, it can fulfil both social and market demands.

Keywords
Agricultural machine, Computer simulation, Mechanical design, Manufacturing, Peeling machine.

1.Introduction
Pineapple is a popular agricultural commodity in Vietnam, with significant economic value. The food and drink industry cultivates approximately 30 million tons of pineapples annually [1–3]. You can consume pineapple raw, dry it, and prepare it in various ways. People consume pineapple as a popular fruit or use it to produce preserves, candy, cakes, and sweets. In order to enhance productivity and achieve cost savings, the utilization of a pineapple peeler during the processing phase has proven to be highly efficient, resulting in a significant time reduction [4–7]. Furthermore, the implementation of automated pineapple peeling improves convenience for various stakeholders in their daily routines, including restaurants, small-scale processing enterprises, and households. The objective of this study is to investigate and devise an affordable pineapple peeler that is appropriate for the economic circumstances in Vietnam. The objective is to enhance productivity and the quality of products while simultaneously decreasing time and costs in comparison to conventional manual peeling techniques. Simultaneously, the aforementioned machine possesses the ability to address the constraints inherent in current machines available on the market, with the objective of promoting extensive production. The paper presents a methodology for designing and evaluating a cost-effective pineapple peeling machine model that maintains high levels of productivity and quality.

The paper is organized as follows: Section 2 discusses the literature review. Section 3 presents the complete process of designing the prototype, from three-dimensional (3D) design to the simulation of strength and deformation. The manufacturing results and experimental results, which demonstrate the capability of the proposed design, are discussed in Section 4. Section 5 covers the discussion on the impact of the proposed design. The conclusion and future work are presented in Section 6.

2.Literature review
In recent years, Vietnam has seen a surge in research projects focusing on the development of peeling machines designed for various fruit types, including apples, lychees, aloe vera, and lotus seeds. Le and Le

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have developed an automatic system that includes an automatic filleting, peeling and dicing mechanism to avoid crushing and reduce manual contact to maintain the good quality of the interior of the aloe vera leaves [8]. Xu et al. utilized water jets to process lotus seeds which provided a high quality of lotus seeds peeled [9]. Le et al. applied two rollers with a pressing belt to separate the peel from the lychee fruit [10]. Xinjie et al. researched characteristics of Fuji apples which provided basic data for research and development of apple harvesting, grading, packaging, and transportation machinery and equipment [11]. These studies have produced promising results, demonstrating the efficacy of these machines in enhancing production processes.

In Vietnam, there has been a presence of industrial pineapple peeling machines on the market for a considerable period, predominantly supplied by commercial enterprises [4–7]. However, this comes at the expense of high production costs and limited adaptability in practical applications. In [12], Madhankumar et al. presented the process of placing the pineapple onto the tray, which requires approximately 5 seconds. The pineapple-cutting process typically takes approximately 15 seconds in total. It’s not fast enough to consider that it’s a semiautomatic machine. Jongyingcharoen et al. [13] presented a prototype machine comprised of four primary modules, namely cutting, gripping, peeling, and pneumatic control. The machine has the capacity to accommodate pineapples of different diameters, with the pineapple's axis aligned parallel to the motion of a cylindrical knife. During the operation, the cutting unit initially removed the ends of the pineapple. Subsequently, the grippers maintained a horizontal orientation of the pineapple as it underwent peeling by the unit's tubular knife. Based on the results of the performance testing, the prototype machine demonstrated a peeling capacity of around 530 fruits per hour, achieving an effectiveness rate of 98.2%. However, this machine is quite bulky, and the control system is not easy to manufacture. The paper from [14] proposed automated pineapple peeling. The machine underwent testing to assess its proficiency in peeling pineapples, slicing them to a consistent thickness, and extracting the central core. The mean duration required to remove the skin, cut it into pieces, and remove the core of a pineapple is 37 seconds. The machine's slicing efficiency varies between 71.5% and 80.0%, with an average slicing efficiency of 74.7%. The machine's throughput capacity varies between 74.7 kg/hour and 95.2 kg/hour, with an average of 83.5 kg/hour. Siriwardhana and Wijewardane [15] presented a pineapple peeler with dimensions of 300 mm, 400 mm, and 220 mm. The weight of the machine is 10 kg, and the stand is 6.5 kg. The machine requires a single operator and completes the task of peeling a pineapple in a time span of 20 seconds. Therefore, the machine allows a lone operator to efficiently peel the entire daily capacity of pineapples (3333 pineapples) in approximately less than 1.85 hours. This machine is also heavy, and the cutting time is slow. In [16], Anjali et al. developed a straightforward, partially automated pineapple peeling machine that is user-friendly, low-maintenance, and cost-effective. The peeler efficiently eliminates the peel, facilitating subsequent processing. In [17], Madhankumar et al. implemented a pineapple peeler machine to address the challenges faced by small and medium-sized businesses by removing the leaves and the core of the pineapple and peeling the outer surface of the fruit.

All the research discussed is either expensive or difficult to fabricate and control. Nevertheless, it should be noted that in the context of pineapple production in Vietnam, a developing country, there has been a lack of research and development efforts dedicated to the creation of a specialized machine. The objective of this article is to present a complete process for developing and manufacturing a pineapple cutting machine with a core-punching mechanism that meets the requirements of food safety, technical specifications, worker suitability, and cost-effectiveness in comparison to existing pineapple cutting machines available in the market. Additional criteria encompass the imperative of preserving the integrity of the pineapple during the cutting process, thereby avoiding any detrimental effects such as bruising or crushing. Furthermore, the task of peeling should be facilitated through a straightforward operation, ensuring ease of control for the user.

3.Method

Machine design is an essential field that involves the design, development, and improvement of mechanical systems and parts. Engineering principles, scientific knowledge, and practical considerations are applied to design machines with specific purposes. Tung et al. fabricated a multipurpose 6-degree-of-freedom robot arm that can be used in various areas [18]. Ceccarelli et al. presented a prototype to help arm movements in rehabilitation therapies and movement exercises [19]. In [20–23], the authors employed 3D design techniques and simulations using Solidworks, or Siemen's NX (also known as NX Unigraphics, or UG), to design various mechanical systems.

In order to design an effective pineapple peeler, the mechanical and physical properties of the pineapple need to be considered. Based on surveys from [24–26], it has been shown that a typical pineapple intended for export or consumption, weighing approximately 0.9kg to 1.2kg, exhibits an average diameter of approximately 110mm and an average length of approximately 160mm. Thus, the pineapple size chosen for this study is approximately 1kg in weight and 110mm in diameter.

It is necessary to examine the mechanical properties of pineapple peel and core [27–30]. Excessive force damages the pineapple core, while insufficient force fails to penetrate the pineapple skin [31–34]. Wei et al. simulated internal mechanical damage in pineapple compression using two multi-scale finite element models [35]. This result can be used as a reference to design suitable mechanisms for picking and peeling pineapples. In [36–38], the authors have carefully analyzed the characteristics of pineapple. From there, it could be determined that the maximum force is needed so that the pineapple will not be damaged when picked up by mechanical mechanisms. In this study, to effectively remove the skin and core of a pineapple using mechanical means, it is necessary to apply an impact force of at least 127 Newtons (N). This ensures that the cut portion remains intact and does not undergo any deformation or crushing, thereby preserving its structural integrity. The structure and preferred morphology of the pineapple.

The article presents a machine structure, as depicted in *Figure 1*, that integrates the necessary specifications for pineapple peeling in industrial applications. The machine fulfills various criteria, including simplicity, ease of manufacturing, ease of cleaning, and low production costs. The material for all parts except the screws is aluminum 6063 for food safety purposes.

The main operational principle of the machine is that the pineapple is severed at its upper and lower extremities before being positioned on the pedestal (6). Subsequently, the pneumatic cylinder (3) is activated, generating a propulsive force. The push rod (5) that is connected to the piston rod serves the purpose of exerting force to propel the pineapple towards the stationary cutting knife set (2). The core and entirety of the pineapple are acquired.

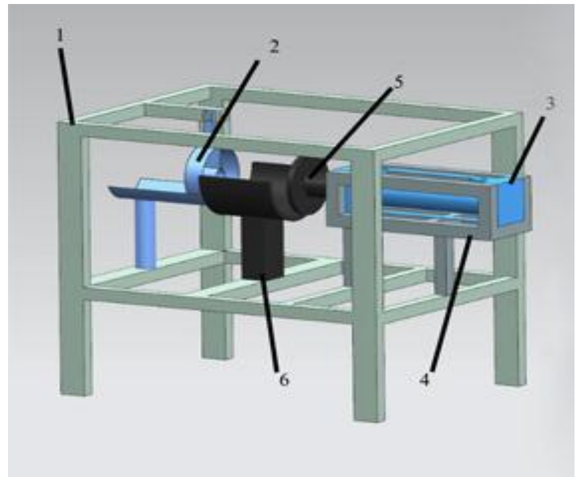

Figure 1 Pineapple peeling machine

3.1Pneumatic cylinder design

Following the surveys in [39–42], it has been determined that cylinders available in the market possess a minimum operating pressure of 0.05 MPa. Therefore, the input pressure for cylinders is selected in accordance with the prevailing standards. By analyzing empirical data and consulting scholarly sources, it is evident that the requisite cutting force for the complete severance of a pineapple must exceed 500 N as shown in Equation 1.

$$F_{xl}=P_t\times A \quad (1)$$

where F_{XL} denotes a force, P_t represents pressure and A is the cross section of the cylinder.

$$A=\frac{500}{8\times10^5}=6.25\times10^{-4}(m^2)$$

$A=\pi\times\frac{D^2}{4}$ in which D is diameter of the cylinder (mm)

$$A=\pi\times\frac{D^2}{4}>6.25\times10^{-4}$$

$$3.14\times\frac{D^2}{4}>6.25\times10^{-4} \Rightarrow D>0.028m=28mm \quad (2)$$

According to the requirements, it is recommended to select the SMC CDA2L50-160Z cylinder depicted in *Figure 2*. The specification of the cylinder is shown in *Table 1*.

Table 1 Cylinder's specification

Specification	Value	Unit
Applicable fluids	Air	mm
Operating method	Double acting	kg
Proof pressure	1.5	MPA
Maximum operating pressure	1.0	MPA
Operating piston speed	50 to 500	mm/s

Figure 2 SMC CDA2L50-160Z cylinder

3.2Cylinder frame design

The dimensions of the cylinder, in terms of height and width, are both 70mm. Therefore, in order to accommodate the cylinder, a fixing frame must have dimensions that exceed 70mm in both height and width. The dimensions of the cylinder frame to be designed have been determined to be 90mm in both height and width. *Figure 3* illustrates the comprehensive excitation analysis of the cylinder support frame. Before the manufacturing process, performing simulation estimates is an essential stage for evaluating the strength of machine components. Chan et al. applied finite element analysis to ANSYS software to verify the strength of a giant machine tool [43]. Tung et al. also used finite element analysis (FEA) on LS-Dyna software to analyze the performance of a mini-CNC milling machine [44]. Yuan et al. especially applied a refined FEA to study the stick-slip friction contact behavior of bolted joint interfaces [45]. This study also performs a deformation test on the cylindrical frame using material parameters derived from the primary frame material, namely the 6063 T5 aluminum profile, to prevent the prototype from falling apart. The simulation results presented in *Figure 4* illustrate the deformation of the cylinder frame. The maximum observed deformation measures approximately 4.1 μm, demonstrating that the structure possesses sufficient stiffness.

3.3Machine frame design

Based on the parameters described, the piston stroke is set at 160mm, which coincidentally matches the standard dimensions of an average pineapple, measuring 160mm in length and 110mm in diameter. The cylinder's piston length measures 160mm, thus necessitating a support base with a minimum length exceeding 200mm for proper fixation. The desired length measurement can be chosen by considering the length of the pineapple after removing both ends. The knife's length required for both cutting and holding the pineapple is undetermined. The length of the machine frame is chosen as L = 540 mm.

Based on the parameters, the inclusion of a fixed aluminum frame measuring 20×20mm will augment the height of the cylinder assembly, initially set at 70mm. Considering the specified height of the cylinder at 110mm, the anticipated height of the machining knife set is unclear in your text. The overall height, denoted as H, measures 450 millimeters. Based on the given parameters, the total width of the cylinder is determined to be 70mm. Additionally, a rigid aluminum frame with dimensions of 20×20mm has been added. The height of the cylinder set is denoted as L, which is equal to 110mm. Furthermore, the diameter of the knife is specified to be 100mm. The diameter of the base measures 150mm. And then the machine's width is set at 400mm. Based on the computed parameters, the comprehensive measurements of the machine frame are presented in *Figure 5*, providing a detailed depiction. *Figure 6* shows the machine frame deformation simulation.

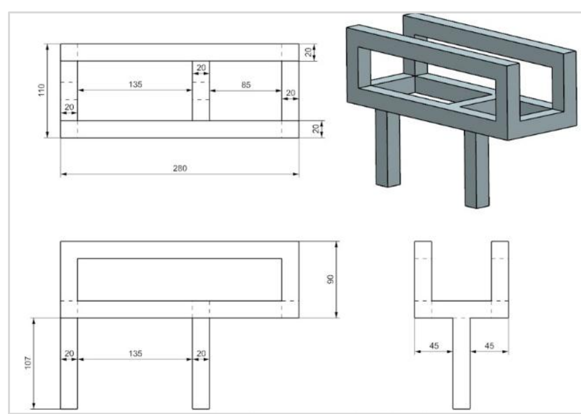

Figure 3 Cylinder frame dimension

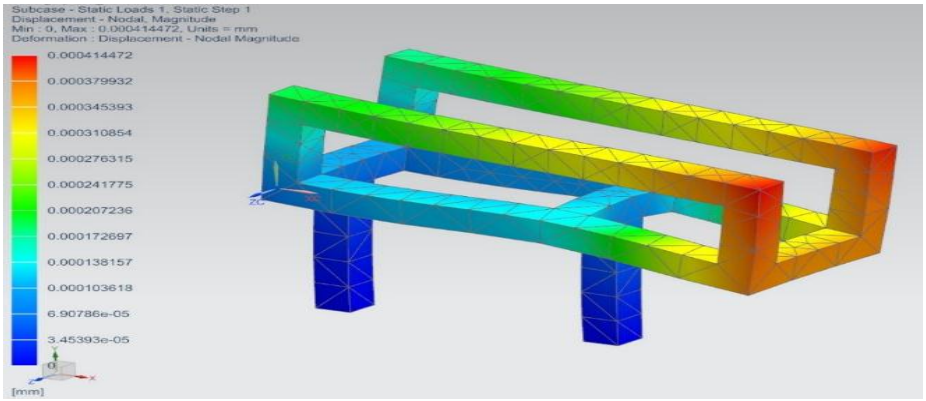

Figure 4 Cylinder frame deformation simulation

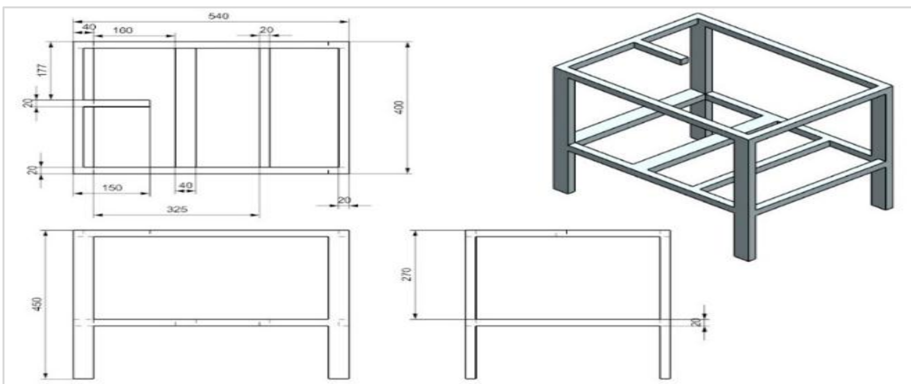

Figure 5 Machine's frame

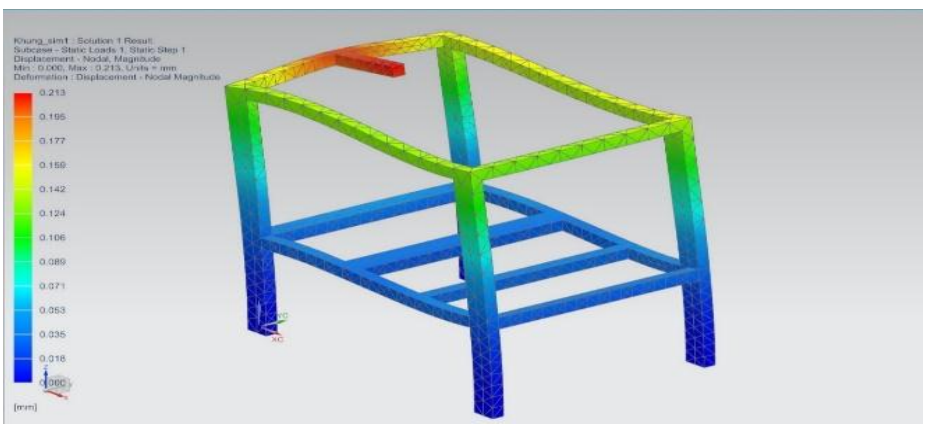

Figure 6 Machine frame deformation simulation

A deformation test was performed on the chassis, revealing that the maximum deformation observed was 0.213mm. This level of deformation falls within an acceptable range and does not have any discernible impact on the operational functionality of the chassis.

3.4Machine frame design

The average diameter of a standard pineapple is measured to be 110mm, while the diameter of the pineapple eye is found to be 10mm. Consequently, the knife diameter required for cutting the pineapple would be 100mm. Therefore, the diameter of the core cutter is set at 25mm.The predicted height of the knife set to be processed is 270mm, thus necessitating a length of 170 mm to secure the knife to the machine frame.The detailed dimensions of the pineapple peeling knife are illustrated in *Figure 7*.

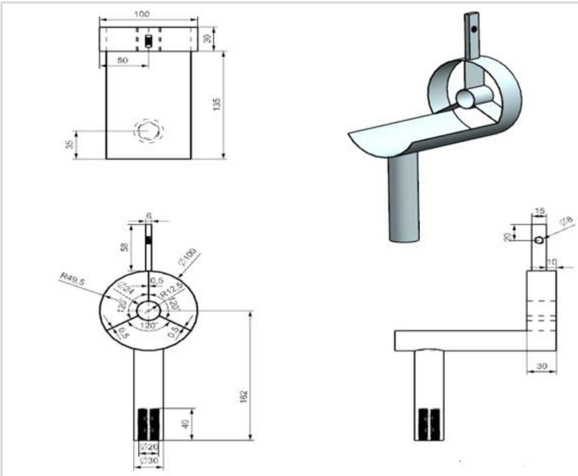

Figure 7 Pineapple peeling knife

3.5Push bar design

According to the calculation, the diameter of the pineapple peeling knife is determined to be 100mm. Consequently, it can be inferred that the diameter of the push bar is also 100mm. The cylinder rod has a diameter of 18mm, which implies that the hole for supplying the push rod to the cylinder rod also has a diameter of 18mm. Additionally, the thickness of the hole is 10mm. The prescribed thread length is 50mm, thus requiring a hole length of 50mm to establish a connection with the push rod. The push rod has a length of 60 mm. The shape and dimensions of the push rod are illustrated in *Figure 8.*

3.6Pineapple trough design

The mean diameter of a typical pineapple is 110mm, thus necessitating the design of a pineapple support with a diameter of 110mm. The base diameter, which includes a 6mm thickness, should be set at 150mm. The diameter of the pineapple's eye measures 10mm, thus necessitating a pedestal height that is 10mm lower than the knife's position. Consequently, the height of the trough is determined to be 100mm, as shown in the *Figure 9.*

4.Results

3D printing is an advanced, rapid, and cost-effective manufacturing technique able to produce many complex machine parts. In [46–49], the authors used 3D printing techniques for plastic parts that are not subject to load or are subject to light load. A prototype of a pineapple cutting machine was developed, as depicted in *Figure 10*. The machine frame and cylinder support frame are constructed through the utilization of aluminum profiles and fastening mechanisms. The cutting process is performed using the bending method, while the support trough is fabricated using the 3D printing method.

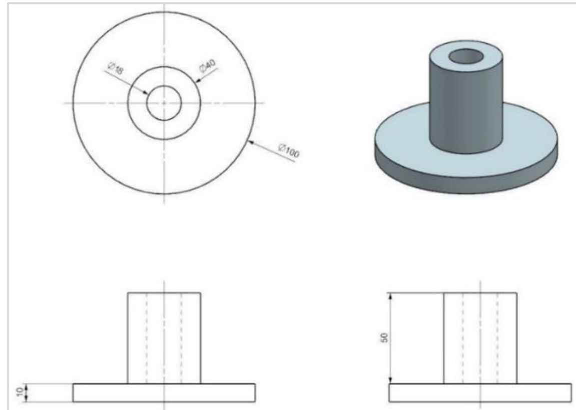

Figure 8 Push bar

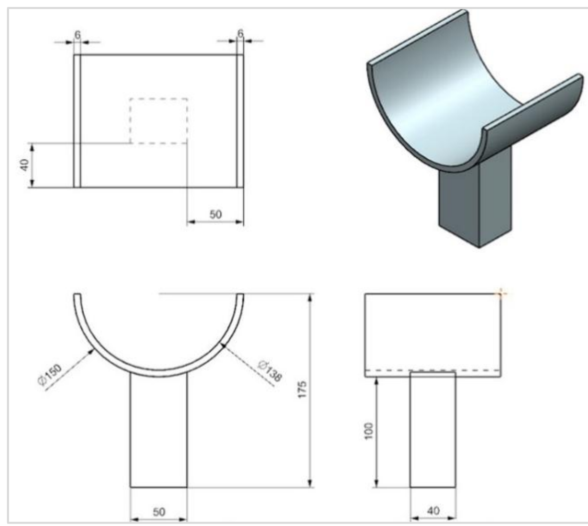

Figure 9 Pineapple trough design

In the process of conducting an experiment including a pineapple, an input pressure of 8 bars was applied. The obtained results are presented in *Figures 11* and *12*. The push bar allows the movement of the pineapple towards the cutting knife, making the peeling process smooth and without excessive damage. The peeling of the pineapple has been finished with success. The pineapple is divided into distinct portions, with the cutter delineating the shape. This process effectively separates the core and peel from the fruit. The mean duration for cutting a pineapple, with an average diameter of 110 mm, is 2 seconds. The machine exhibits compatibility with industrial applications and is well-suited for large-scale manufacturing processes.

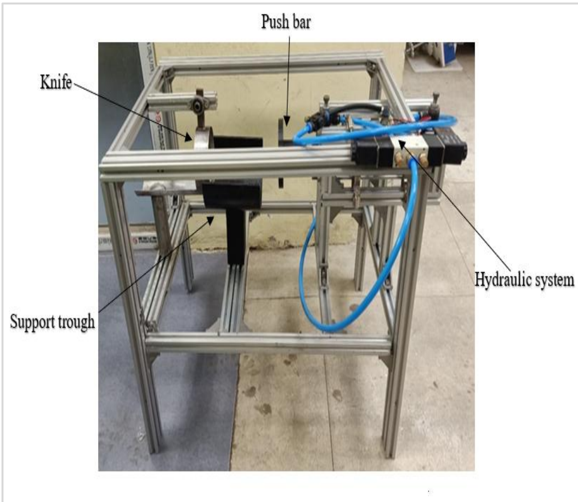

Figure 10 A prototype of pineapple peeling Machine

Figure 11 Pineapple cutting process

The utilization of this pineapple peeler expedites the efficient elimination of pineapple skin throughout the peeling procedure. Therefore, this aids in improving labor productivity and minimizing costs to the maximum extent. The prototype's specifications are summarized in *Table 2*. The experiment was conducted with two cases of cutting by hand and cutting by the proposed machine. Each case cuts 5 fruits. The cutting time results are shown in *Table 3*. The percentage of loss is shown in *Table 4.* Before use, the machine is disinfected with regular disinfectant solution or 90% alcohol.

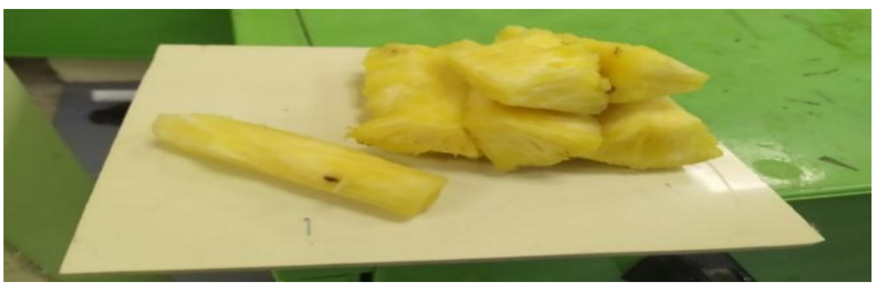

Figure 12 The final product

Table 2 Prototype's specifications

Specification	Value	Unit
Size	500×450×450	mm
Weight	8	kg
Pressure	0.5 ÷ 1.5	MPA
Cutting time	2	Second
Average pineapple diameter	110	mm

Table 3 Experimental results in peeling time by hand versus machine

	By hand		By machine	
Sample	**Pineapple diameter (mm)**	**Cutting time (s)**	**Pineapple diameter (mm)**	**Cutting time (s)**
1	106	182	110	2.5
2	112	179	108	2.0
3	111	180	113	2.4
4	107	176	111	2.2
5	110	181	109	2.5

Table 4 Percentage of loss in peeling by hand versus machine

Sample	By hand			By machine		
	Pineapple weight (kg)	**Peeling weight (s)**	**Percent (%)**	**Pineapple weight (kg)**	**Peeling weight (s)**	**Percent (%)**
1	1.03	0.46	44.7	1.05	0.5	47.6
2	1.11	0.51	45.9	1.07	0.49	45.8
3	1.09	0.47	43.1	1.04	0.46	44.2
4	1.06	0.49	46.2	1.08	0.51	47.2
5	0.98	0.45	45.9	1.02	0.48	47.1

5.Discussion

The product has an open design, making it convenient for cleaning and maintenance. Furthermore, the control system is simple, with only on-and-off switches for controlling the pneumatic cylinder.

Furthermore, the machine demonstrates cost-effectiveness compared to other commercial products (KA-720P, Sunshine Machinery, Xinshijia), as shown in *Table 5*. It also offers simplicity in maintenance and assembly, making it well-suited to the prevailing economic conditions in Vietnam.

Table 5 Price comparison of proposed machine with commercial products

Pineapple cutting machine	Price (USD)
Proposed machine	729
KA 720P (Japan)	6000
Sunshine Machinery (China)	4200 – 4800
XINSHIJIA Peeling machine (China)	2200 - 3200

Limitations

While experimental results indicate that machine cutting is more time-efficient than hand cutting, the percentage of loss is not significantly different. The reason is that the shape of each pineapple is different and the way the pineapple is installed on the machine also has a lot of influence. In addition, the installation of pineapples on the machine is being done by hand leading to low productivity. Moreover, at this state of the machine, the design is not considered the environmental aspect as well as safety operation.

A complete list of abbreviations is listed in *Appendix I*.

6.Conclusion and future work

This paper discusses the analytical development of a pineapple peeling machine, combining the principles of the core punch mechanism. The main working part of the machine consists of a pushing bar and a cutting blade. This hybrid design was selected in order to reduce the cutting time. The mechanical properties of pineapple were studied thoroughly in terms of size, shape, and mass density. This information was used as the basis for the design and strength analysis of the prototype. The results showed that the impact force needed to successfully cut is 127 N. The machine has been developed according to the standardized dimensions of pineapples commonly employed in industrial manufacturing processes. After checking the strength and deformation properties guaranteed by numerical simulation, a prototype was successfully manufactured. The machine possesses a straightforward design and operates seamlessly in order to fulfill the requirements of pineapple peeling for manufacturing purposes. Experimental results showed the effectiveness of the proposed machine compared to working by hand. It’s shown that the cutting time is only 2 seconds. Furthermore, the price summary has shown the economic efficiency of the proposed prototype compared to commercial products.

Nevertheless, the machine's efficacy is limited to pineapples with a diameter of approximately 110mm. Future work improvements include redesigning the cutting blade to accommodate various sizes of pineapples, implementing an automated pineapple feeding system, and incorporating an automatic product retrieval mechanism after cutting to enhance the efficiency of the machine system.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

The data may be provided by the corresponding author upon reasonable request.

Author’s contribution statement

Tran Thanh Tung: Writing, software, original draft preparation, investigation, experiment, manufacturing, design, simulation. **Tran Vu Minh**: Conceptualization, methodology, supervision, reviewing and editing.

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Appendix I

S. No.	Abbreviation	Description
1	3D	Three-Dimensional
2	FEA	Finite Element Analysis
3	N	Newtons
4	UG	Siemen's NX