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Research article

Design and development of continuous pineapple-peeling machine

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Abstract

Importance of the work: A continuous pineapple peeler was designed having a mechanism to align the pineapple during peeling for use in small to medium-sized enterprises.

Objectives: To design, fabricate and test the performance of a continuous pineapple peeler based on the physical and mechanical properties of pineapples.

Materials & Methods: The physical and mechanical properties of pineapples were investigated, specifically their dimensions, the forces required to cut the ends and for peeling, and the bioyield force. A continuous pineapple-peeling machine was designed and developed. The offset of the fruit core centerline and the centerline of the cut fruit were investigated to evaluate machine performance.

Results: The prototype machine consisted of four main units (cutting, gripping, peeling and pneumatic control). The most important part of the design was the V-shaped grippers angled at 90° that were driven by a rack and pinion mechanism. The machine could hold pineapples of various diameters with the axis of the pineapple aligned with the movement of a tubular knife. During operation, the pineapple ends were first removed by a cutting unit. Then, the grippers held the pineapple horizontally while it was peeled by the unit's tubular knife. From performance testing, the prototype machine had a peeling capacity of approximately 530 fruits/h, with an effectiveness of 98.2%.

Main finding: With the mechanism to align the pineapple during peeling developed in this study, the continuous pineapple-peeling machine had high peeling capacity and high effectiveness, making it acceptable by fresh pineapple processors.

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Introduction

Pineapples (*Ananas comosus* [L.] Merr.) are a major economic crop in Thailand, with their total production being approximately 1.98 million t in 2021, of which approximately 0.89 million t went to domestic consumption and 1.09 million t were further processed (Bureau of Agricultural Commodities Promotion and Management, 2022). Thailand is currently the world's fourth largest exporter of pineapples, with the popular pineapple variety for canned products being Pattawia and popular varieties for fresh-cut products are Trat Si Thong, Thong Rayong, Phuket, Phu Lae and Sawee. Thai pineapple standards for fresh-cut products specify the characteristics of the variety in terms of shape, color, smell and taste, with the average weight of a pineapple not less than 250 g for small size varieties (National Bureau of Agricultural Commodity and Food Standards, 2003).

Today, the pineapple processing industry is using commercially available peelers, such as Ginaca-type machines, most of which work by first peeling and then cutting out the core. First, a pineapple without a crown is passed through a sharp rotating tube for peeling. Then, the pineapple is cylindrical in shape with a diameter equal to the tubular knife used for peeling. After that, both ends of the pineapple are cut and the core removed (Lobo and Paull, 2017). The typical peeling machine is automatic and has a maximum peeling rate of 300 kg/hr (Tropical Food Machinery, 2021). However, these peelers are very expensive and not suitable for small and medium-sized enterprises. Smaller pneumatically operated pineapple-peeling machines have been developed (Arsad, 2012; Prakasha et al., 2017; Shinde et al., 2017; Anjali et al., 2019) to reduce workload and labor, shorten production time and reduce labor fatigue. A pneumatic cylinder is used to push a sharp-edged tubular knife through an appropriately placed pineapple (Prakasha et al., 2017; Shinde et al., 2017). Another pneumatic cylinder is used to push a knife to trim the ends of the pineapple. In one design, the pineapple core is cut using a pneumatically driven tubular knife. Another pineapple peeler was developed to push a tubular knife through a vertically positioned pineapple, producing a cylindrical shape (Kumar, 2014). However, there are frequently offsets between the centerline of the core and the fruit circumference. This is a critical quality problem in the production of peeled pineapples as these machines do not have a mechanism to align the pineapple during peeling. Thus, a mechanism for holding the pineapple and aligning it with the axis of the sharp tube for peeling is particularly desirable.

Knowledge of the physical and mechanical properties of materials undergoing processing is critical for the design of equipment for harvesting, cleaning, sorting, grading, peeling, cutting and packaging agricultural products (Ceccarelli et al., 2000; Emadi et al., 2009; Ahanbakhshi et al., 2018). For mechanical peeling, cutting tools are designed using the geometric characteristics of the products and the mechanical properties of their skin (Li, 2020). Xia et al. (2012) developed a pineapple harvest apparatus. The main part of the clamping mechanism was a set of V-shaped fingers set apart by 120°. Performance testing indicated that the V-shaped fingers provided stable and reliable clamping. Qian et al. (2018) designed a pineapple-picking mechanism based on the shutter mechanism principle. A shutter was opened and closed to hold, screw and pick a pineapple. However, it is very important that the applied forces of the gripper do not exceed the permissible damage threshold of the fruit (Li et al., 2011).

The current research involved a case study of an airline catering operation, in which an average of 2,000 kg/d of Phuket pineapples are prepared and trimmed for flight service. However, fresh-cut processing is labor intensive. It begins by removing both ends of the pineapple with a knife, applying force through a sharp cylindrical tube to a vertically positioned pineapple, and using a knife to trim the pineapple cylinder to the desired dimensions. When using manual labor in the peeling process, it was found that the distance between the core center and the center of the fruit circumference was too large. Thus, the objectives of the current research were: 1) to determine the physical and mechanical properties of pineapples for the design of a peeling machine; and 2) to design, fabricate and test the performance of a continuous pineapple peeler to address these problems.

Materials and Methods

Pineapple samples and preparation

The pineapples were of the Phuket variety that had been harvested at least 140 d since flowering stimulus had been applied. They were obtained from a caterer whose specifications must follow airline requirements that require no crown or stem (Fig. 1). The pineapple samples were stored at 25 °C and used within 1 d of receipt.

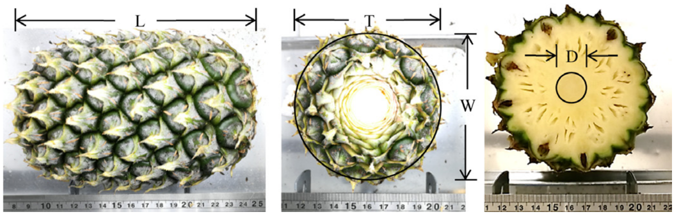

Fig. 1 Sample of length (L), major diameter (W), minor diameter (T), and core diameter (D) of studied pineapples, where scale bar is in centimeters

Physical and mechanical properties of pineapples

The physical properties of 200 pineapples were sampled, involving weighing each fruit (accuracy ±0.01 kg). The physical properties of each fruit were determined (length, major diameter and minor diameter) according to Mohsenin (1970). The pineapples were cut crosswise to measure their core diameter. The dimensions and projected area of the samples were evaluated using image analysis (modified from Ercisli et al., 2012). A digital camera (EOS 77D; Canon; Japan) was installed on a light box. The sample was placed in the light box and under the center focus of the camera. The dimensions of the sample images were analyzed using the Image J program using a standard ruler for calibration (Image J, The National Institutes of Health, USA). Roundness of the pineapple cross-sections was determined based on Equation 1:

$$Roundness = \frac{A_p}{A_c} \quad (1)$$

where A_p is the largest projected area of an object in a natural resting position and A_c is the area of the smallest circumscribed circle.

The mechanical properties of the pineapples were determined using a texture analyzer (TA.HDplus; Stable Micro Systems; UK). Measurements consisted of compression force for cutting the ends of pineapple, compression force for peeling and bioyield force. A sample of 20 pineapples was used for each test. Each pineapple was placed horizontally on the cutting blade set (Fig. 2A). Both ends of the pineapple were simultaneously cut at a velocity of 50 cm/min. The maximum force required for cutting the ends of the pineapples was recorded. As shown in Fig. 2B, each pineapple was tested for its maximum compression force for peeling by placing the pineapple fruit vertically on a sharp 6 cm diameter peeling tube. The texture analyzer was used to press the pineapple through the peeling tube at a velocity of 50 cm/min. The bioyield force was evaluated using compression testing (American Society of Agricultural Engineering, 2008) by horizontally placing the pineapple samples on a base plate (Fig. 2C). Each sample was compressed using a parallel plate probe at 10 mm/min until the sample ruptured. The force-deformation behavior was recorded and the bioyield force was determined from the analysis. Typical force-deformation curves of these mechanical tests are shown in Fig. 3.

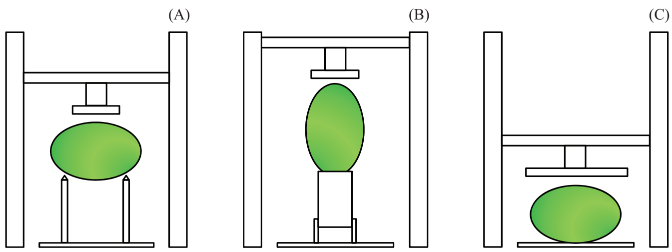

Fig. 2 Diagrammatic representation of force testing of pineapples: (A) cutting ends; (B) peeling; (C) compression

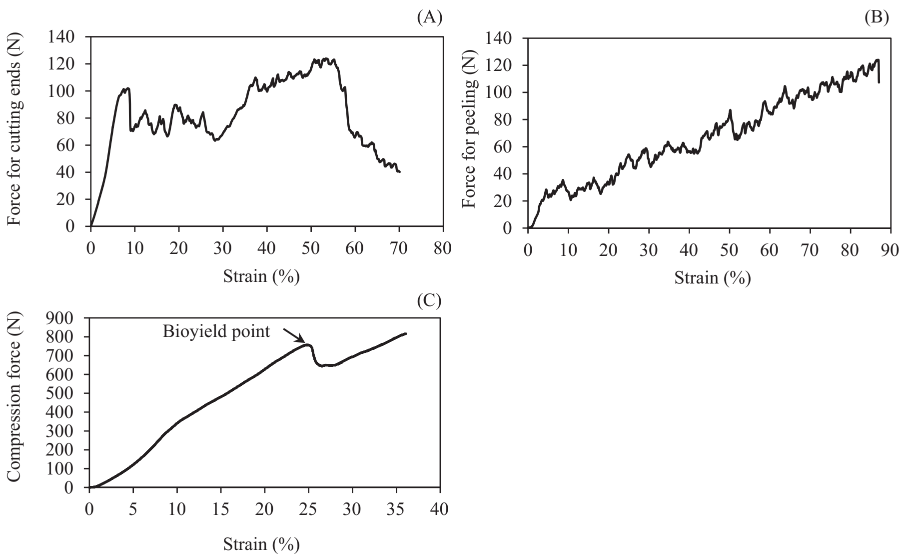

Fig. 3 Typical force-deformation curves for testing pineapples: (A) cutting ends; (B) peeling; (C) bioyield force

Design and operation of the continuous pineapple-peeling machine

Several important requirements were considered in the design of the continuous pineapple peeler. First, the pineapple cylinder was 6 cm in diameter and 13 cm in length. These dimensions were set so that they were less than the minimum length and diameter of the pineapples used in the study. Second, the centerlines of the pineapple cylinder and core were not more than 3 mm apart (Fig. 4), in accordance with the airline catering requirements. Third, the machine was entirely operated using a pneumatic system. Last, the machine could be operated by a single person.

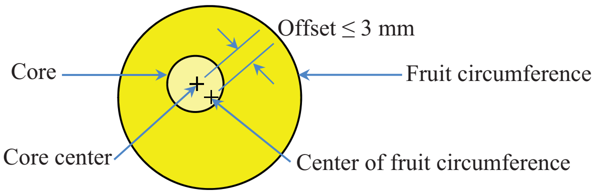

Fig. 4 Offset of fruit core centerline and centerline of fruit circumference

The major components of the machine were: 1) end-cutting unit, 2) gripping unit, 3) peeling unit and 4) pneumatic control unit, as depicted in Fig. 5. The pineapple end-cutting unit (Fig. 6) consisted of a V-shaped support base with a 90° groove and double knives for cutting both ends. The sum of the contact forces (F_{c1}) between the V-shaped support base and the pineapple created a net force perpendicular to the knives, moving the pineapple towards the knives. The V-shaped support base was mounted to a rod at the end of the first pneumatic cylinder. The support base moved the pineapple upward through the two knives, whose edges had been sharpened to an angle of 30° and were separated by 13 cm to simultaneously cut both ends of the pineapple. The diameter of the first pneumatic cylinder was calculated using Equations 2, 3 and 4. It was found that the maximum force for cutting the ends of the pineapples was 124.01 N. The design force for the pineapple end-cutting unit was defined as 10 times the experimental force obtained from mechanical property testing.

$$F_d = F_{th} - F_r \tag{2}$$

$$F_{th} = A \times P \tag{3}$$

$$A = \frac{\pi D^2}{4} \tag{4}$$

where F_d is the designed force for each operation (N), F_{th} is the theoretical piston force (N), F_r is the frictional force (N) equal to approximately 10% of theoretical piston force, A is the desired piston area (measured in square meters), P is the working pressure (in pascals) and D is the cylinder diameter (in meters).

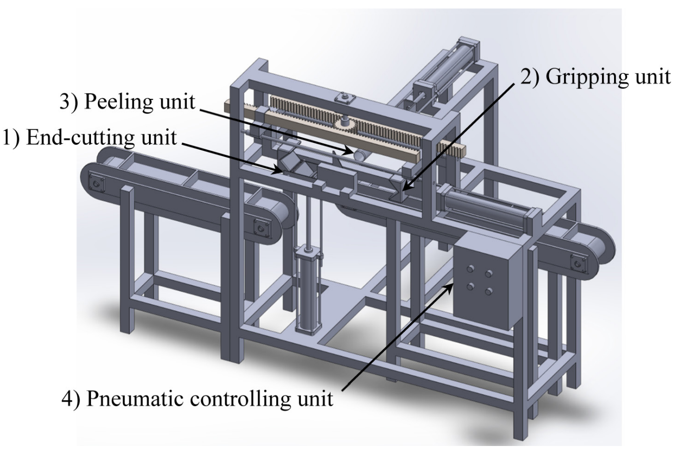

Fig. 5 Continuous pineapple-peeling machine

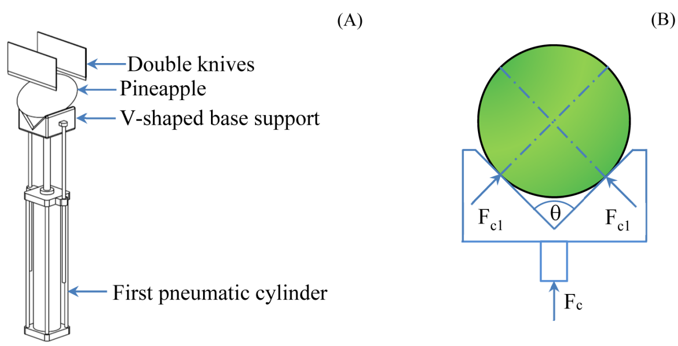

Fig. 6 (A) Pineapple end-cutting unit; (B) schematic diagram of V-shaped base support forces acting on pineapple, where F_{c1} = contact force between the V-shaped support base and a pineapple

The pineapple gripping unit consisted of grippers adjusted using a rack and pinion mechanism. The grippers (Fig. 7) were V-shaped with opposing planes angled at 90º. When the rod of the second pneumatic cylinder moved forward to drive the rack and pinion, the left gripper moved the pineapple along the rack until both grippers held the pineapple. The axis of the pineapple was aligned with the direction of a tubular knife (Fig. 8). The grippers generated four contact forces (F_{c2}) on a pineapple, with each force being equally distributed around the fruit circumference to maintain its shape. The gripping force (F_g) should not cause a significant deformation of the pineapple as this may damage the fruit. The diameter of the second pneumatic cylinder for pineapple gripping was calculated using Equations 2, 3 and 4. Based on the results of compression testing, the gripper exerted a force of 340.98 N so that it caused no more than 10% strain. This force was less than that for bioyield, so no bruising occurred.

While the gripper held the pineapple horizontally, the rod of the third pneumatic cylinder moved a tubular knife through the pineapple to peel it. After that, the peeled pineapple was within the tubular knife. While the rod retracted, a plunger pushed the pineapple cylinder out of the knife and the product continued to an outlet conveyor. Concurrently, the rod of the second pneumatic cylinder moved back and the grippers released the pineapple peel. The designed force for pineapple peeling was 10 times that of the peeling test (127.02 N). Equations 2, 3 and 4 were used to calculate the diameter of the third pneumatic cylinder.

The stage design of the pneumatic system for controlling the continuous pineapple-peeling machine is shown in Fig. 9. The working gauge pressure of the pneumatic system was 700 kPa. Data for the calculation and selection of pneumatic cylinders in the pineapple peeling processes for cutting, gripping and peeling are shown in Table 1.

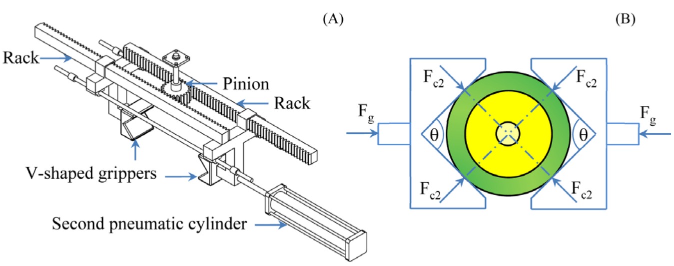

Fig. 7 (A) Pineapple gripping unit; (B) schematic diagram of forces of V-shaped grippers acting on a pineapple, where F_{c2} = contact force generated by the gripper on a pineapple

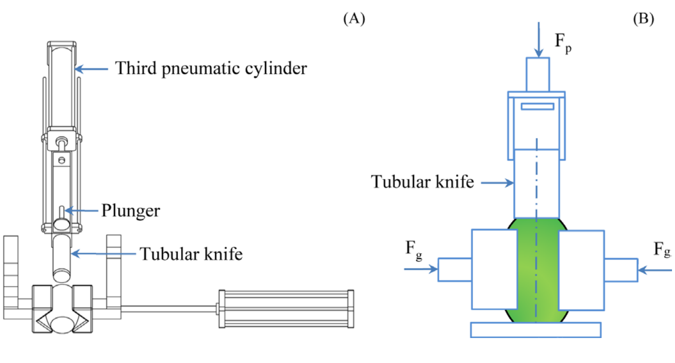

Fig. 8 (A) Pineapple peeling unit; (B) alignment of pineapple and tubular knife, where F_g = gripping force and F_p = maximum force for peeling

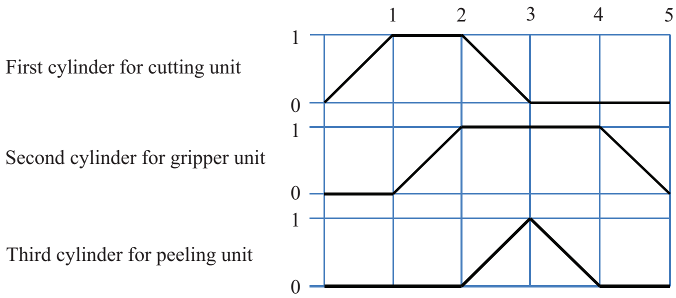

Fig. 9 Stage diagram of cylinders for continuous pineapple-peeling machine

Table 1 Design parameters for continuous pineapple-peeling machine

Operation	Parameter	Value
Cutting	Maximum force for cutting ends (F_c)	124.01 N
	Designed force for cutting ends (10 times F_c)	1,240.1 N
	Minimum cylinder diameter for cutting ends	50.06 mm
Gripping	Designed force for gripping (F_g)	340.98 N
	Maximum cylinder diameter for gripping	26.25 mm
Peeling	Maximum force for peeling (F_p)	127.02 N
	Designed force for peeling (10 times F_p)	1,270.2 N
	Minimum cylinder diameter for peeling	50.67 mm

The operational process of the continuous pineapple-peeling machine is shown in Fig. 5. The machine started with the horizontal placement of a pineapple on the inlet conveyor belt. Then, the pineapple was transported to the end-cutting unit. The rods of the first pneumatic cylinder with a V-shaped support base moved the pineapple upward toward the double knives to remove both ends of the pineapple. Then, the pineapple entered the gripping unit. The rod of the second pneumatic cylinder pushed the grippers to hold the pineapple horizontally, so that the axis of the pineapple was correctly oriented in the movement direction of the tubular knife. The rod of the third pneumatic cylinder moved the larger tubular knife horizontally through the pineapple to peel it. As the rod of the third pneumatic cylinder moved back, a plunger pressed the cylindrical-shaped pineapple out of the tubular knife. Finally, the pineapple cylinder exited the machine *via* an outlet conveyor unit. The rod of the second pneumatic cylinder moved back and the grippers release the pineapple peel to another outlet.

Performance evaluation of the continuous pineapple-peeling machine

For performance evaluation of the continuous pineapple-peeling machine, the piston speed was set at 20 cm/s for both cutting and peeling units, while the piston speed of the gripping unit was 5 cm/s. A sample of 100 hundred pineapples was peeled using the machine designed in the current study. The process began with cutting away both ends of the pineapples and then peeling them. Details of all operations are shown above. The operation time was recorded and the average capacity of the continuous pineapple-peeling machine was evaluated. Acceptable samples were determined by counting the pineapple cylinders having core and cylinder centerline offsets of less than 3 mm. Then, the effectiveness of peeling was determined based on the percentage of acceptable samples. The human resources for preparing the pineapple cylinders were also used as a control parameter of the machine.

Statistical analysis

The data were presented as mean values ± SD. All data were analyzed using the SPSS software package (Version 26; IBM; USA). Pearson's correlation coefficient was used to represent the relationship between variables.

Results and Discussion

Table 2 shows the physical and mechanical properties of the Phuket pineapple sampled. All data had a standard normal distribution. The mean, median and mode values of each dataset were similar. For physical properties of the outer portion of the pineapples, the mean values of length, major diameter, minor diameter and mass were 17.60±1.15 cm, 10.31±0.69 cm, 10.32±0.70 cm and 1.75±0.37 kg, respectively. The ratio of the major-to-minor diameters was 1.0009, while the coefficient of determination was 0.8484 (Fig. 10). These data indicated that the cross-section of the pineapples was nominally circular and that the major and minor diameters of the pineapple were positively correlated (Table 3). Similarly, the roundness of the pineapple cross-section was almost 1. The Pearson's correlation coefficient was 0.923 at a significance level of $p < 0.01$. This correlation was the same as that of a study of the physical properties of tomatoes (Lak et al., 2018). However, the length of the pineapple was not correlated with

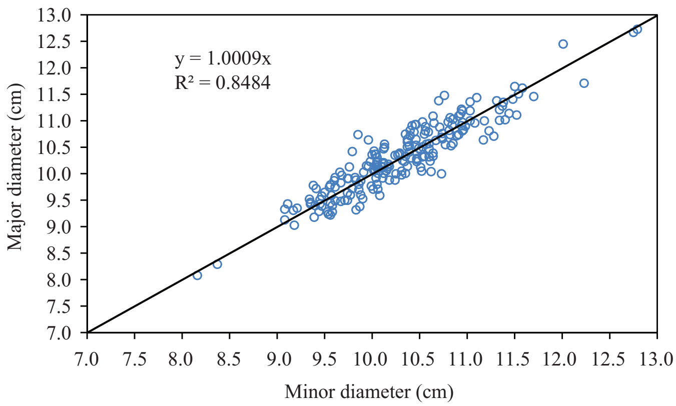

Fig. 10 Plot of major and minor diameters of pineapples, where R^2 = coefficient of determination

Table 3 Correlation coefficients between length, major diameter and minor diameter of pineapples

Dimension	Length	Major diameter	Minor diameter
Length	1	-	-
Major diameter	0.060^{ns}	1	-
Minor diameter	0.047^{ns}	0.923*	1

* Correlation is significant at $p < 0.01$ (2-tailed); ns = non-significant

Table 2 Physical and mechanical properties of pineapples

Physical property	Maximum	Minimum	Mean±SD	Median	Mode
Length (cm)	21.33	14.66	17.60±1.15	17.34	17.16
Major diameter (cm)	12.79	8.16	10.31±0.69	10.30	10.14
Minor diameter (cm)	12.73	8.08	10.32±0.70	10.30	10.04
Mass (kg)	1.63	1.22	1.45±0.37	1.40	1.48
Roundness (cm^2/cm^2)	1.00	0.92	0.98±0.02	0.98	0.99
Core diameter (cm)	2.73	1.23	1.82±0.28	1.77	1.46
Force for end cutting (N)	124.01	70.12	93.13±14.48	90.50	88.00
Force for peeling (N)	127.02	72.22	97.65±12.21	98.00	96.00
Bioyield force (N)	775.87	755.76	765.82±14.22	763.22	762.87

its major and minor axis diameters ($p > 0.05$). The length-to-diameter ratio of the Phuket pineapples was 1.71.

In the mechanical testing of pineapples, the mean force for cutting the ends, the mean force for peeling and the mean bioyield force were 93.13±14.48 N, 97.65±12.21 N and 765.82±14.22 N, respectively. Physical property data of the pineapples were used to design the dimensions of the continuous pineapple peeler, including for the V-shaped support base and gripper. Additionally, the mechanical properties of the pineapples were used to calculate the diameters of the pneumatic cylinders for each unit operation. For the gripper design, the designed force could not exceed the bioyield force because such a high force causes cells to rupture (Li et al., 2017). Therefore, the mean force value (340.98 ± 12.48 N) at a strain of 10%, was selected in the current study for calculation of the diameters of the pneumatic cylinders of the gripper unit.

The performance of the continuous pineapple-peeling machine was assessed by peeling 100 pineapples. This revealed that peeled pineapples were cylindrical with an average diameter of 6 cm and an average length of 13 cm (Fig. 11). Cutting was done with the designed tubular knife and two double knives; 98.2% of the pineapples peeled by the developed machine had acceptably small distances (≤ 3 mm) between the center of the core and the center of the fruit circumference, meeting the quality criteria of the fresh pineapple processors. This percentage was far better than the original process where only 65.3% of samples met this acceptance criterion. The prototype machine used an average operation time of 6.8±0.75 s/fruit or a capacity of approximately 530 fruits/h (Table 4). This capacity was double that of a single person manually peeling pineapples, while the developed machine had a far lower defect rate. Thus, using this machine would be quite beneficial to fresh pineapple processors.

In conclusion, the data obtained regarding the physical and mechanical properties of pineapples were very useful in the development of a continuous pineapple peeler. Performance testing confirmed that this machine was successful and should be useful to small and medium-sized enterprises.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

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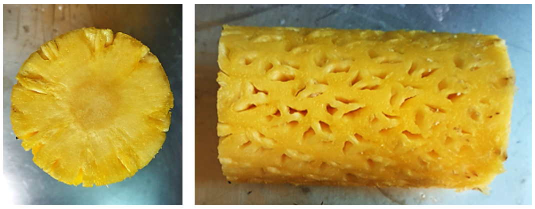

Fig. 11 Pineapple cylinder produced by prototype machine

Table 4 Comparison of performance of pineapple-peeling machine versus manual process

Type	Capacity (fruits/h)	Effectiveness of peeling (%)
Manual process	257	65.3
Machine	530	98.2

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