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An automatic trimming machine for young coconut fruit

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A prototype automatic young coconut fruit trimming machine was designed, constructed, tested and evaluated. The mechanism used features a sharp inclined knife which operates in translation motion in a vertical plane to trim the fruit, which is clamped tightly and rotates about a vertical axis. Machine components include a main frame, a body-trimming station, a shoulder-trimming station, a base-cutting station, a rotary base, three fruit holders, an electrical connection slip ring, a power drive and programmable electronic control. In experiments, the untrimmed fruit was continuously fed into three separate fruit holders. These in turn conveyed the coconut through the body-trimming, shoulder-trimming and base-cutting stations. The fruit holders continuously travelled in a circle encompassing every station in sequence. Optimal settings included (a) feeding rate of 86 fruit h⁻¹, (b) 300 rpm rotation of the trimmed fruit, and (c) a shoulder knife height of 180 mm. Average loss rates were 0.35%, for the fibrous area, 2.5% for fruit damage and 14.5% for the untrimmed green area. The optimally trimmed fruit was accepted by growers and traders.

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1. Introduction

Young “Namhom” coconut is an international favourite. The fruit consists of a husk enclosing shell, flesh and juice. Normally, the fruit is manually trimmed into a pentagonal profile to remove the husk. Manual trimming requires considerable physical strength and a very large sharp knife, and thus is a dangerous procedure. Other problems associated with manual trimming are the shortage of skilled labour and the considerable amount of time that the trimming procedure takes.

Accordingly, several researchers have attempted to develop a young coconut fruit trimming machine (Harach and

Jarimopas, 1995; Jarimopas and Pechsamai, 2002). Unfortunately, their machines were unacceptable to growers, processors and traders. However, more recently, Jarimopas and Ruttanadat (2007) developed a prototype of young coconut fruit trimming machine which appeared to have more potential. The machine was based on the lathe cutting machine mechanism and was composed of a lathe machine with a body-trimming knife, a shoulder-trimming knife, a base-cutting knife, and clamping mechanisms. The prototype had the capacity to trim 21 fruit h⁻¹, with the finished product on average containing 1.1% of untrimmed green area and 0.2% of fibrous area. The fruits trimmed by the machine were accepted by fruit traders and exporters. However, about

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70% of machine operating time was lost because of the need to manually reposition and hold the fruit, and readjust the knife for each trimming operation. As a result, it proved faster to manually trim fruit than to use the machine.

To consume their flesh and the juice, trimmed coconuts must be opened either manually or mechanically. As with trimming, manual opening requires the use of a large sharp knife, and physical strength and presents injury risks for the opener. Jarimopas and Kuson (2007) developed a young coconut fruit opening machine. The machine worked on the concept that opening was achieved by shearing the rotating trimmed young coconut by a stationary knife. The opening machine performance was attributed by the capacity of 30 s/fruit, juice spill-off of 2%, sawdust in juice of 0.2 g, diameter of circular opening of 58 mm. However, development of young coconut opening machine challenges the further development of the automatic young coconut fruit trimming machine to work better and faster than manual operators. Thus, the present research was aimed to develop an automatic young coconut fruit trimming machine which can process the fruit efficiently and quickly.

2. Materials and methods

2.1. Determination of physical characteristics of intact and trimmed young coconut fruit

2.1.1. Physical characteristics of the coconut samples

A number of young coconut fully mature fruit of the “Namhom” variety were obtained. Thirty intact and 30 trimmed young coconut fruit were randomly selected from three big fruit markets in the Bangkok metropolitan area (10 from each location). The diameter D and height H of each intact fruit were measured using vernier callipers (Figs. 1 and 2). The physical characteristics of each trimmed fruit sample (fruit height h_1 , shoulder height h_2 , shoulder diameter dh ,

base diameter db) were then measured. The intact and the trimmed samples were sectioned along the stem axis using a saw and a large sharp knife (Fig. 2). Following this, a selected half sample that had been arranged horizontally was photographed using an Olympus C750 Ultra zoom digital camera (Olympus Corp., Japan). The dimensions of the young coconut were then measured using the Measure Tool (I) function in the Adobe Photoshop CS (Adobe Systems Inc., CA, USA) computer software application (Jansomwong & Jaroenpru, 2002). The position of shell in the intact fruit as compared to that in the trimmed fruit was determined as well. Knowledge of the physical characteristics described above was essential to the design of the automatic young coconut fruit trimming machine. The complete list of characteristics was as follows:

For intact fruit (dimensions in mm)

H = fruit height

D = fruit diameter

h = shell height

d = shell diameter

b_1 = vertical distance between the stem and the shell

b_2 = vertical distance between the shell and the fruit base

a_1 = horizontal distance between the fruit skin and the shell on the left side

a_2 = horizontal distance between the fruit skin and the shell on the right side

For the trimmed fruit (dimension in mm)

h_1 = fruit height

d = shell diameter

g_1 = shoulder height on the left side

g_2 = shoulder height on the right side

dh = shoulder diameter

db = base diameter

j_1 = vertical distance between crest and shell

j_2 = vertical distance between shell and base

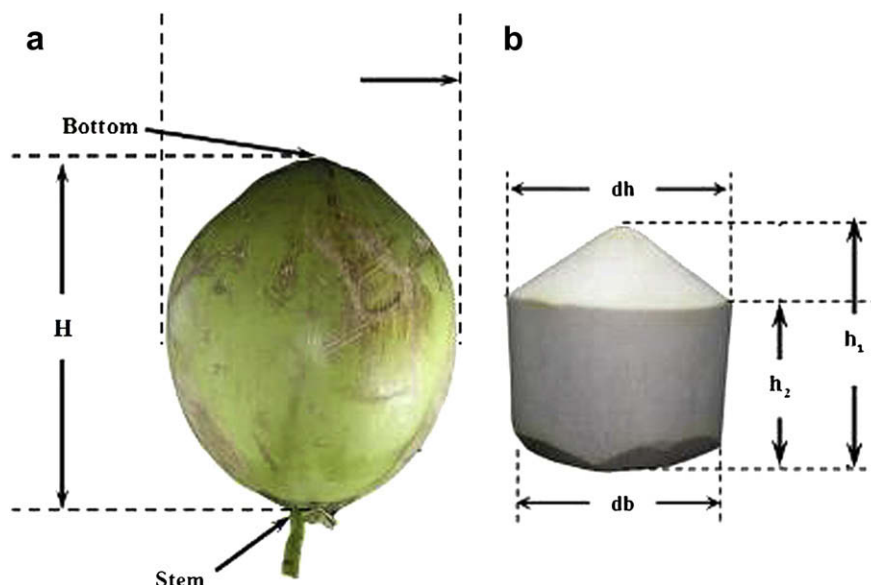


Fig. 1 – Images of intact and a trimmed young coconut fruit. (a) Intact and (b) trimmed.

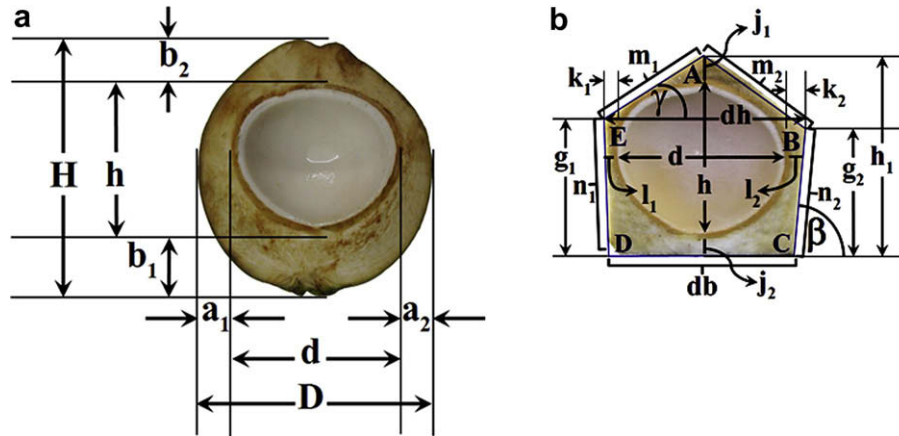


Fig. 2 – Sectioning of young coconut fruit with labelling of its dimensions. (a) Intact and (b) trimmed.

k_1 = horizontal distance between shoulder and shell on the left side

k_2 = horizontal distance between shoulder and shell on the right side

l_1 = the narrowest horizontal distance between skin and shell on the left side

l_2 = the narrowest horizontal distance between skin and shell on the right side

m_1 = distance between crest and shoulder on the left side

m_2 = distance between crest and shoulder on the right side

n_1 = distance between shoulder and base on the left side

n_2 = distance between shoulder and base on the right side

γ = shoulder angle \widehat{AEB}

β = base angle = $180 - \widehat{BCD}$

h_2 = average shoulder height = $(g_1 + g_2)/2$

$k = (k_1 + k_2)/2$; $l = (l_1 + l_2)/2$; $m = (m_1 + m_2)/2$; $n = (n_1 + n_2)/2$

After determining the relevant physical characteristics, mechanical trimming was simulated using the SolidWorks 2007 software (Dassault Systemes SolidWorks Corp., MA, USA) using the methods described in detail in Ruttanadat and Jarimopas (2008).

2.1.2. Size distribution

Three hundred and seventy intact young “Namhom” coconuts at full maturity were purchased randomly from a big exporting orchard at Baanpaew in Samutsakohn province. H and D of all the samples were measured and analysed using the descriptive statistics supported by SPSS 12 for Windows (SPSS Inc., IL, USA).

2.2. Design and operation

2.2.1. Design

The design concept was to trim the clamped, vertically rotating fruit by applying an inclined sharp knife in translation motion in a vertical plane. The prototype (Fig. 3) consisted of a body-trimming station, a shoulder-trimming station, and a base-cutting station, all mounted 120° apart on a fixed main frame around the periphery of a rotary base (a

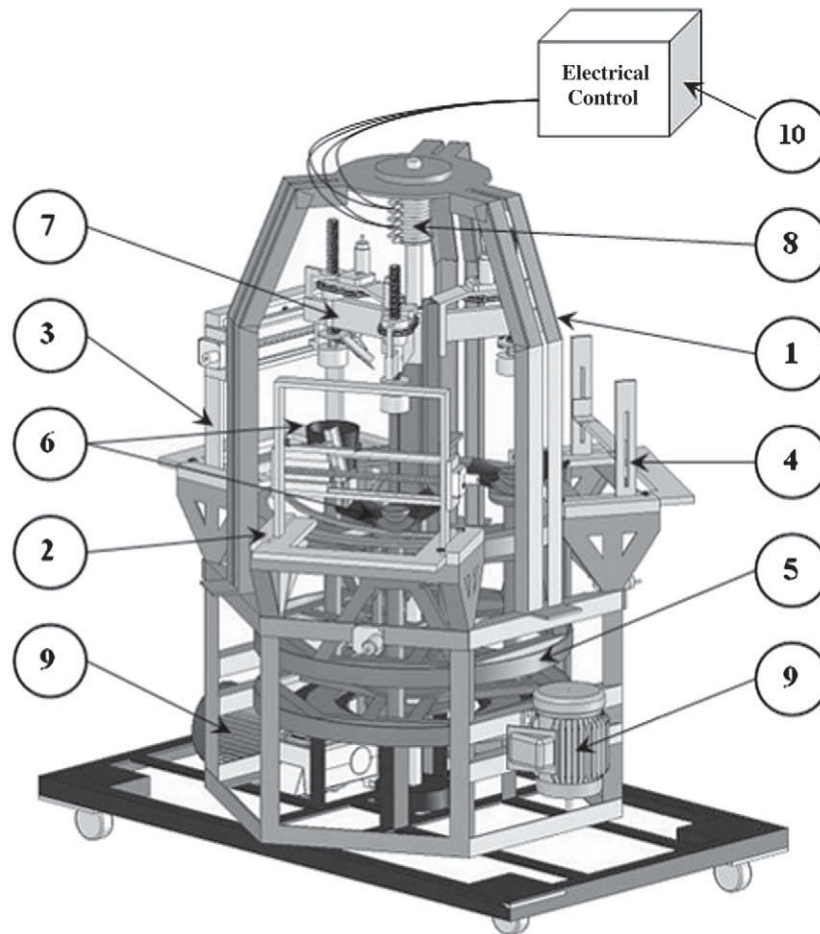
turntable). Mounted on the turntable, also 120° apart, were three identical fruit holders. Each fruit holder (Fig. 4) included a top and the bottom piece.

The bottom piece consisted of a circular platform in the middle and was surrounded by three movable jaws. Each jaw was lined with foam rubber to reduce damage to the fruit. The jaws could be opened or closed in order to facilitate the trimming by knives of the body and shoulder of the fruit. The function of the top piece was to clamp the fruit and located associated with the fruit holder. The top piece comprised a shaft, spring, limit switch, and a DC motor to drive the shaft.

The spring, the limit switch and the motor were installed on the shaft, the end of which was capped with a rubber cone. The function of this cone was to tighten the top of the untrimmed fruit, or the crest of the trimmed fruit. The spring provided fruit compression while the limit switch controlled the compression. Each fruit holder could automatically change the fruit holding configuration to facilitate trimming of different parts of the fruit as the fruit moved from one station to the next. For example, the top and the bottom pieces together compressed the fruit at the body-trimming (Fig. 5b) and the base-cutting station (Fig. 6). The three jaws grasping the trimmed body of the fruit on the bottom piece only without the top piece (Fig. 7b).

The fruit holder also functioned as a spindle that rotated the fruit about its vertical axis during the trimming operation. All motions and synchronisations of the machine components were control by motors, limit switches, and a programmable logic controller (PLC). The birdcage-shape main frame was 1 m wide by 1.7 m long by 1.7 m high and stood on a steel platform which rode on four small wheels. The main frame was made of 50 mm steel L-beams. The body-trimming station (Fig. 5) included the trimming knife, which was mounted on a feeding mechanism driven by a DC motor and controlled by limit switches.

The shoulder-trimming station (Fig. 7) was in principle similar to the body-trimming station. The inclination angle of the body-trimming knife and the shoulder-trimming knife was set according to Jarimopas and Ruttanadat (2007). The base-cutting station (Fig. 6) featured a sharp straight knife



No.	List
1	Main frame
2	Body trimming station
3	Shoulder trimming station
4	Input-output-base cutting station
5	Rotary base
6	Fruit holder
7	Fruit pressing set
8	Slip Ring
9	Electrical motors
10	Electrical control

Fig. 3 – The prototype automatic young coconut fruit trimming machine.

mounted on a feeding mechanism similar to that of the other two stations. Cutting of the fruit base was performed automatically while input of the untrimmed fruit and the removal of the trimmed fruit were carried out manually by the operator at the base-cutting station.

The rotary base (Fig. 4) conveyed the young coconut to be processed from one station to the other station until the completion of trimming. This component revolved at a speed of 8.8 rpm. It was equipped with a 37.5 mm shaft driving the fruit holder to turn at a speed of 300 rpm.

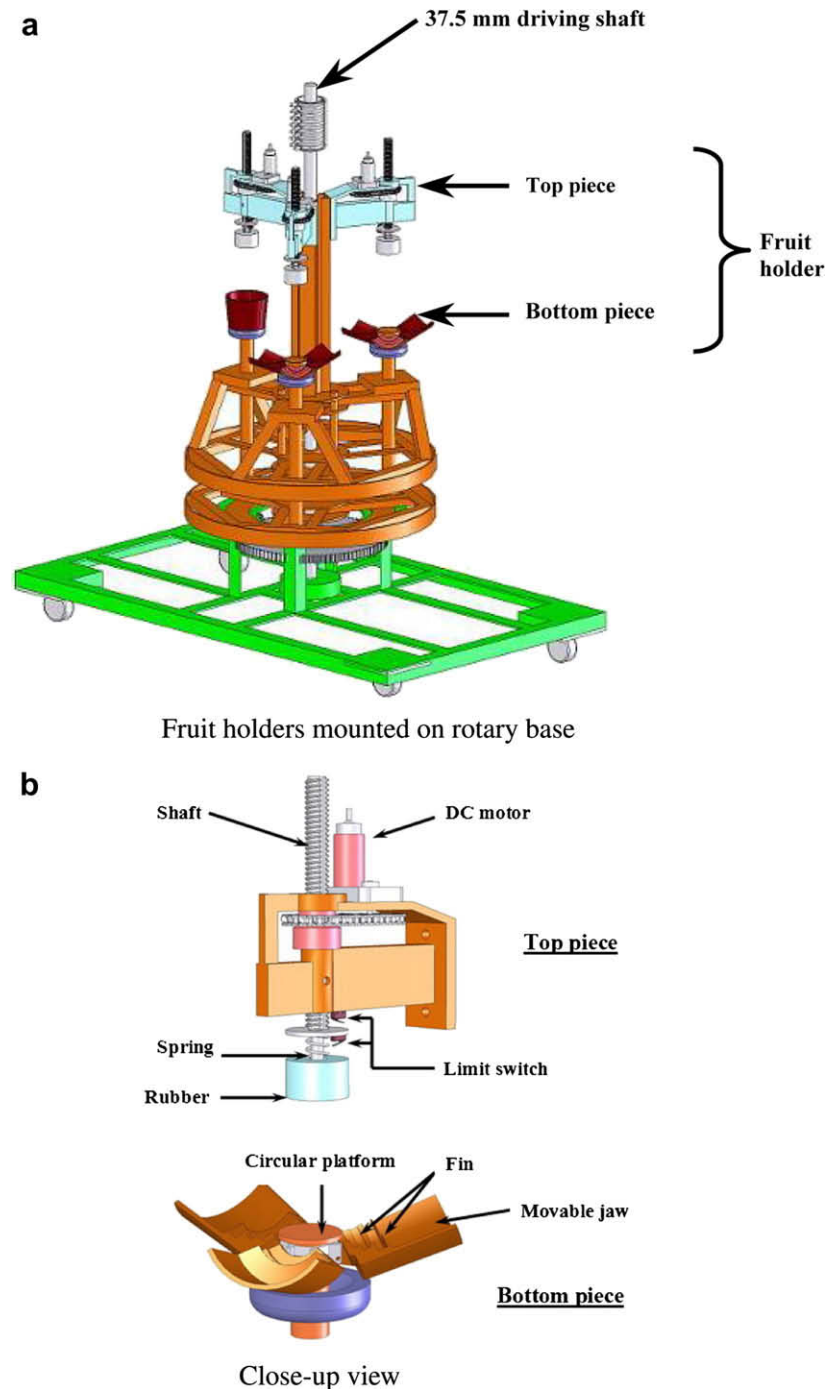


Fig. 4 – Rotary base with fruit holders. (a) Fruit holders mounted on rotary base and (b) close-up view.

The slip ring of the electrical connection was made of PVC tubes. The inner tube was equipped with 14 brass rings while the outer tube was equipped with carbon brushes. The brush and the ring were preferred as a method of forming electrical contact as it was felt that electrical wires may become entangled during rotation. Power for the system was provided by a 3 hp, 380 V brake motor driving the rotary base turning at 8 rpm and a 3 hp, 380 V electric motor powering shafts rotating the fruit holders at 300 rpm. The power transmitted through gears and all mechanisms was controlled by two

PLCs. The DC motor used in the machine was a commonly used and easily maintained 12/24 V, 110/300 rpm unit.

2.2.2. Operation

The operator firstly loaded the untrimmed coconut (fruit No. 1) onto the fruit holder/spindle at the base-cutting station, which also served as an input–output station. At this station, the fruit was clamped from the top and bottom (Fig. 8) by the downward movement of the top piece of the holding set. After the fruit was held securely, the operator pressed a control button to

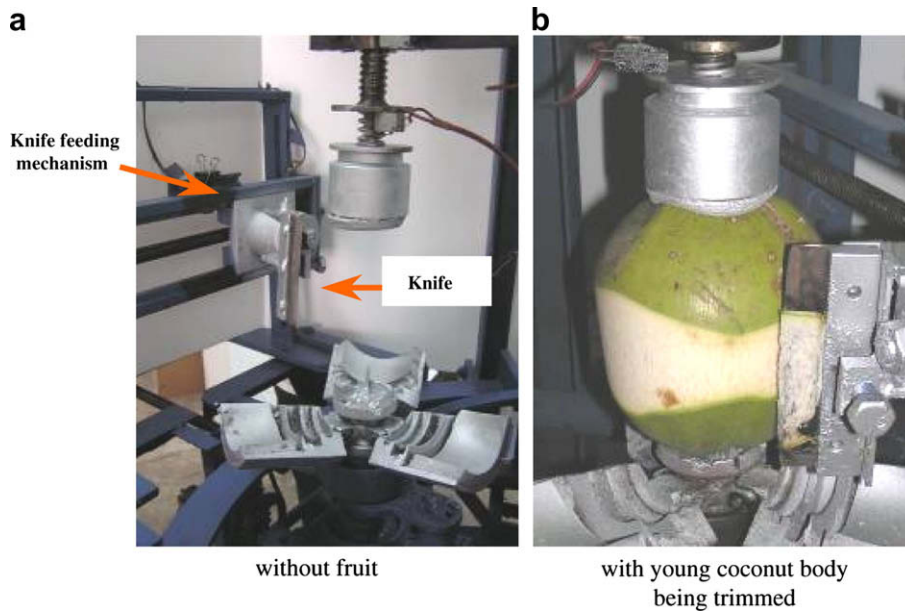


Fig. 5 – Body-trimming station. (a) Without fruit and (b) with young coconut body being trimmed.

start the operation. The fruit started to spin as the turntable rotated 120° to convey the fruit to the body-trimming station where the fruit was trimmed by the body-trimming knife. When the trimming was completed, the machine stopped, and the operator loaded fruit No. 2 onto the second fruit holder at the base-cutting station. The operator then pushed the control button to continue the operation. At this moment, both fruit started to spin, and the turntable rotated 120° to move fruit No. 2 to the body-trimming station and fruit No. 1 to the shoulder-trimming station.

As fruit No. 1 was being conveyed from the body-trimming station to the shoulder-trimming station, the machine automatically changed the holding configuration by pivoting the jaws of the three-jaw grasper to clamp the trimmed body of the fruit, and also raising the top piece of the holding set (Fig. 7). Then the body of fruit No. 2 and the shoulder of fruit No. 1 were trimmed simultaneously. When the trimming was

completed, the machine stopped, and the operator loaded fruit No. 3 onto the third fruit holder and activated the machine again to move fruit No. 1 to the base-cutting station, fruit No. 2 to the shoulder-trimming station, and fruit No. 3 to the body-trimming station.

As fruit No. 1 was being moved to the base-cutting station, the fruit holder returned to the top-and-bottom holding configuration to allow the knife to cut through the base of the fruit. While the base of fruit No. 1 was being cut, the other two fruits were also being trimmed simultaneously. After the base-cutting operation, the trimming of fruit No. 1 was complete, and the machine stopped. The operator removed the trimmed fruit No. 1, loaded a new fruit onto the fruit holder, and pushed the control button to continue the operating cycle. In continuous operation, three coconuts were trimmed simultaneously, one at the body-trimming station, one at the shoulder-trimming station, and one at the base-

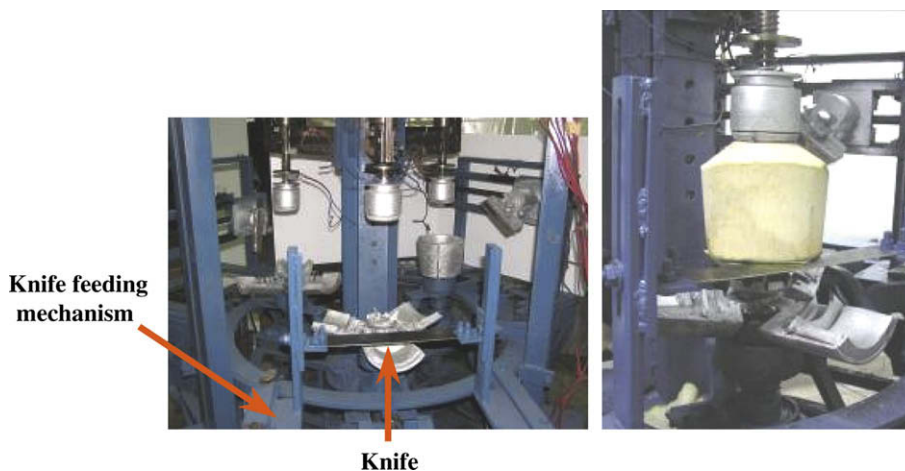


Fig. 6 – Base-cutting station.

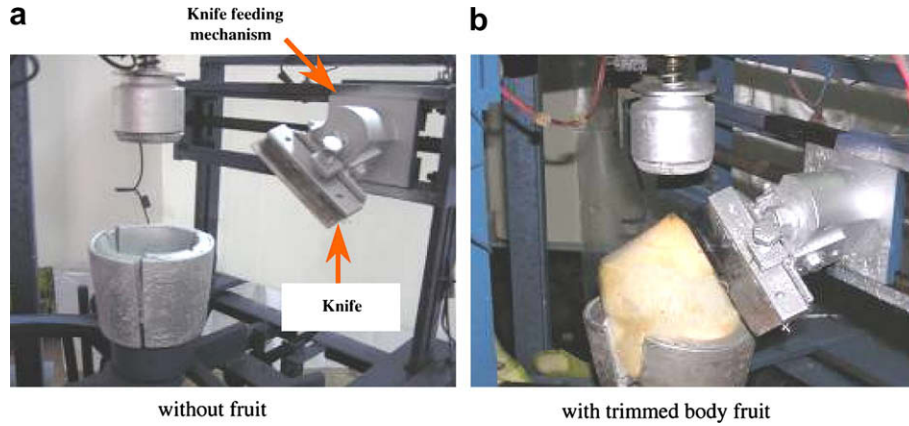


Fig. 7 – Shoulder-trimming station. (a) Without fruit and (b) with trimmed body fruit.

cutting station. The duty of the operator was to remove the finished fruit from the base-cutting station and load a new fruit onto the fruit holder. Then he pressed a control button to activate the system. Each time the control button was pressed, the turntable pivoted 120° to convey the fruit to the next station. As the fruit reached the next station, the spindle rotated the fruit, and the trimming knife moved forward to trim the fruit and then returned to its docking position. At this time the machine stopped so that the operator could remove the finished fruit and load another new fruit at the base-cutting station.

2.3. Performance test

The purpose of the performance testing was to (a) operate the machine and (b) evaluate the correctness and readiness of

cutting station. The automatic trimming machine was switched on and the fruit pressing set descended to clamp the sample. Then, the fruit holder rotated and carried the sample to be trimmed to the body-trimming, shoulder-trimming and base-cutting stations. The operation duration at each station was recorded.

The trimmed sample that was removed from the base-cutting station was dipped into the sodium metabisulfide solution (2.5% concentration) to prevent surface browning. The wet fruit was then left in a room for surface drying and was thereafter weighed and measured. The trimming performance in terms of the remaining green area, the fibrous area, and the number of fruit successfully trimmed was measured and analysed according to Jarimopas and Ruttanadat (2007):

$$\text{Untrimmed green area (\%)} = \frac{\text{the green area marked on transparency plate}}{\text{total trimmed and untrimmed fruit surface area}} \times 100 \tag{1}$$

$$\text{Fibrous area FA (\%)} = \frac{\text{remaining fibrous area}}{\text{total trimmed and untrimmed fruit surface area}} \times 100 \tag{2}$$

$$\text{Machine capacity} = \frac{1}{\text{trimming time}} \tag{3}$$

$$S = (\text{number of fruit whose shell was trimmed}) / (\text{total trimmed fruit}) \times 100$$

performance of the individual parts and the entire system, especially the interaction between the mechanical parts and the programmed electronic control.

Each of the three fruit holders was separately tested with regard to their ability to perform body trimming, shoulder trimming, and base cutting. Twenty newly harvested young coconuts were used. An untrimmed sample with its stem turned down was first mounted to the fruit holder at the base-

The same testing procedure was repeated with the other two fruit holders. A test was carried out to continuously feed 65 untrimmed young coconuts to every fruit holder working simultaneously. This test aimed to determine the optimal operating conditions of the automatic trimming machine.

The final test was the observation of the long-run performance of the automatic trimming machine. The optimal conditions were set constant throughout the long-run



Fig. 8 – Base-cutting station.

operation. This procedure involved the use of 200 newly harvested young coconuts selected at random. The trimming knives were changed after 50 fruits had been trimmed. The trimming machine performance was then evaluated.

3. Results and discussion

3.1. Physical characteristics of the intact and the trimmed young coconut fruit

Tables 1 and 2 present the statistics of physical characteristics of the intact and the trimmed young coconut fruit. On average, intact fruit was 180 mm in height (H) and 160 mm in diameter (D). The height (h) and the diameter (d) of its shell were 99 and 105 mm, respectively. The characteristics of the trimmed fruit were 136 mm height (h_1), 90.0 mm shoulder height (h_2), 126 mm shoulder width (dh), 108 mm base width (db), crest angle (γ) of 35.6° and base angle (β) of 84.4° . The aforementioned physical characteristics were fundamental

data which determined the design of the fruit holder and cutting knife angle settings.

Fig. 9 shows the distribution of height and diameter of the intact young coconut. Mean and median of fruit height (Fig. 9a) were 175.2 ± 10.8 mm and 174.7 mm while that of fruit diameter (Fig. 9b) were 153.1 ± 0.87 mm and 152.1 mm, respectively. The closeness of the mean and the median suggested the histogram distribution was normal (Wanichbancha, 2006). The 175 mm height and the 153 mm diameter of intact fruit were applied for the machine design.

3.2. The automatic trimming machine performance

Each individual fruit holder efficiently transported the untrimmed young coconut through the body, shoulder and base-cutting stations. All the fruit samples were trimmed successfully. Continuous operation suggested that the appropriate operating conditions were (a) a feeding rate of 86 fruit h^{-1} , (b) 300 rpm revolution of the trimmed fruit, and (c) 180 mm shoulder knife height. The shoulder knife height was based on the probability that 90% of young coconut in a normal distribution (Fig. 9) would be medium sized. The machine could automatically trim 200 young coconut in 2.34 h at the throughput capacity of 86 fruit h^{-1} (excluding time for the three separate knife replacements). Testing showed that 0.35% of fibrous area remained, while the average total untrimmed green area was 14.5%. A total of 2.5% of the coconut were damaged through over trimming.

All mechanical parts functioned interactively and efficiently with the programmed electronic control. The trimmed fruit was accepted by growers and traders. The trimmed fruit quality, in term of the fibrous area and untrimmed green area remaining, was higher than that produced by the semi-automatic trimming machine developed by Jarimopas and Ruttanadat (2007). Processing speed in comparison to the average competent manual trimming rate (35 fruit h^{-1}) was also higher.

Table 1 – Physical characteristics of intact young coconut fruit

Characteristics	Dimension (mm)
Fruit height (H)	179.7 ± 5.3
Fruit diameter (D)	160.2 ± 5.6
Shell height (h)	99.3 ± 4.2
Shell diameter (d)	105.3 ± 6.0
Vertical distance between the stem and the shell (b_1)	45.4 ± 5.2
Vertical distance between the shell and the fruit base (b_2)	32.7 ± 2.5
Horizontal distance between the fruit skin and the shell on the left side (a_1)	26.3 ± 3.0
Horizontal distance between the fruit skin and the shell on the right side (a_2)	26.0 ± 2.9

Table 2 – Physical characteristics of trimmed young coconut fruit

Characteristics	Dimension (mm)
Fruit height (h_1)	135.9 ± 6.6
Average shoulder height (h_2)	89.7 ± 4.8
Shell diameter (d)	111.9 ± 7.7
Shell height (h)	106.3 ± 6.9
Shoulder diameter (dh)	126.2 ± 9.0
Base diameter (db)	108.3 ± 9.2
Vertical distance between crest and shell (j_1)	18.2 ± 2.9
Vertical distance between shell and base (j_2)	12.4 ± 4.5
Average horizontal distance between shoulder and shell (k)	14.0 ± 3.5
The average narrowest horizontal distance between skin and shell (l)	5.2 ± 3.8
Average distance between crest and shoulder (m)	84.3 ± 6.8
Average distance between shoulder and base (n)	83.7 ± 10.0
Shoulder angle (γ)	$35.57 \pm 1.93^\circ$
Base angle (β)	$84.44 \pm 1.11^\circ$

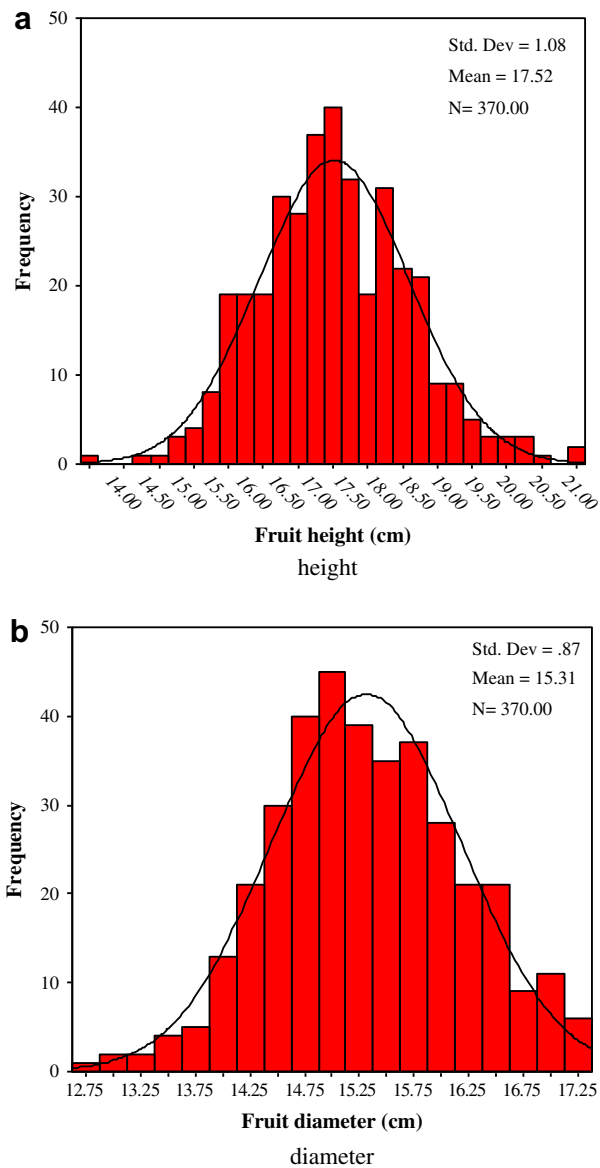


Fig. 9 – Histogram of intact fruit height and diameter distribution. (a) Height and (b) diameter.

4. Conclusion

A prototype of a single operator automatic young coconut fruit trimming machine was designed, constructed, tested and

evaluated. Continuous performance testing revealed a trimming capacity of 86 fruit h⁻¹. The average fibrous area remaining after trimming was 0.35%; the average damage rate was 2.5%; and the average remaining untrimmed green area was 14.5%. Knife changes were necessary after every 50 trimming operations. The throughput capacity was about 2.5 times higher than that of manual trimming by skilled trimmers. The fruit trimmed by the machine prototype was accepted by growers and traders.

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