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Design and performance of young coconut shaping machine

(Reka bentuk dan prestasi mesin pembentuk kelapa muda)

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Keywords: young coconut, trimming and shaping machine, drinking nut

Abstract

The project was initiated to design and develop a prototype of young coconut shaping machine. The main purpose of the design was to trim most of the outer husk (green husk) to create an attractive looking trimmed coconut (hexagonal shape) which could easily be cut open. The prototype machine was based on lathe trimming mechanism which consisted of a pair of blades and bottom-up holder to clamp the young coconut. During operation, the young coconut was placed vertically at the holder and clamped before the body and shoulder trimming took place. When the fruit rotated, the operator manually adjusted the trimming blades to trim the body and shoulder part of the fruit. The rotational speed used for trimming the fruits can be adjusted accordingly. The prototype machine could trim 95 newly harvested fruits per hour when the rotational speed was set at 400 rpm. The percentage of defect was 5% and the knife had to be changed after every 30 nuts.

Introduction

The coconut ranks fourth in Malaysia's agriculture in terms of cultivated area with oil palm, rubber and paddy occupying the greater portion. About 63% of coconut production is for domestic consumption and 37% is for export and industrial processing (Sivapragasam 2008). The coconut industry, however, still plays an important role in the country's economy providing livelihood to some 100,000 farm families or almost 10% of the nation's farming community (Sivapragasam 2008).

In major coconut producing countries, several products and by-products are processed for export. They are coconut fibre: mats, brooms; shell products: activated carbon; coconut-based food products: coconut milk, nata de coco and young tender coconut (Punchihewa and Arancon 1999). In many countries, despite the numerous benefits derived, the coconut is under threat due to factors such as conversion of farms to oil palm, urbanisation and vagaries of market particularly the volatility of its various products (Sivapragasam 2008).

The young coconut fruit can be marketed at two stages of development, mature and immature. At the immature stage, the fruits contain mostly water and a little jelly like meat. The edible part of the coconut fruit (coconut meat and water) is the endosperm tissue. The clear juice inside can be consumed as a refreshing drink. The coconut water contains the same major electrolytes as those in human body fluids (Fife 2007). It has long been the most popular beverage consumed in the tropics

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where it is considered not only a refreshing drink but also as a health tonic (Fife 2007). The juice also contains glucose, vitamins, hormones and mineral which could enhance health and vitality (Yong et al. 2009).

In Malaysia, the major varieties grown are the *Malayan Tall* (92.2%), followed by the hybrid *MATAG* (4.3%), *MAWA* (1.7%), the aromatic *Pandan* (1.7%) and the *Malayan Dwarf* (0.2%) (Sivapragasam 2008). In Thailand, the *Pandan* variety is also known as 'Makprow Nam Horm' (Hakim 2011). However, only four varieties were suggested to be used as tender drinking nuts: *MAWA*, *MATAG*, *Pandan* and *Gading*. Drinking nuts should be harvested earlier at about 7 months after pollination (Phillips 1994). The maturity of the young coconut fruit strongly affects the fruit quality. The juice and the flesh of the immature fruits are sour and over-soft (jelly-like) while the over-mature fruit is considered by consumers to be too sweet and hard (Terdwongworakul et al. 2009).

To retain the freshness and wholesomeness, newly harvested young coconuts are immediately transported to the packing house for trimming of individual nuts. Two cultivars that were recommended by the Ministry of Agriculture (MOA) are *MATAG* and *MAWA* where the fruits have high proportion of husk with long and angular shape. The husk is thickest at the end and in ridges along the length corresponding to the fundamental tricarpellate ovary. Less amount of husk would lead to a shorter, less angular and almost spherical fruit (MOA 2009).

Young coconut is suitable for export to distant countries because the hard shell and husk provide good protection for the flesh and juice inside (Harach and Jarimopas 1995). The young coconut is typically trimmed to remove most of the outer husk, and then wrapped with shrink plastic before being packed in corrugated boxes. Trimming and shaping the young coconut facilitate ease of packaging hence reduce transportation cost.

Currently, the trimming process is done manually which requires skilled labour and extremely hazardous. The operators need to shear the husk off the green fruit with a long sharp knife. The inner white husk is then finely shaped to form a conical shaped top with a slightly tapered cylindrical body and a flat base. In addition to that, the fruit should be at least 6 months old and the trimming process should allow at least 1 cm thickness of husk left on the stem end of the fruit over the soft eye (Mohpraman and Siriphanich 2012). After trimming, the fruit are dipped into sodium metabisulfite solution to prevent surface browning. The concentration of sodium metabisulfite should not be over 5% and the dipping time should not exceed 5 min to ensure that the edible portion of the fruit is safe for consumption (Mohpraman and Siriphanich 2012).

The shortage of skilled labour and the high production cost has created an urgent need for mechanical trimming machines. In fact, many traders have showed interest and desire to have machinery that is capable of trimming the young coconut fruit into an attractive shape similar to that practised by skilled labour. Jarimopas and Ruttanadat (2007) had developed a machine that could trim young coconut into a diamond shape with horizontal trimming mechanism. However, most of the machine operating time was to manually reposition and hold the fruit and readjust the knife for each trimming operation (Jarimopas et al. 2009). In other words, horizontal trimming mechanism was not the best solution in terms of productivity and efficiency.

Therefore, this study was particularly focused on vertical trimming mechanism hence creating a better and safer way to trim young coconut fruit. The aim of the present study was to overcome the limitation of young coconut manual trimming process and to carry out the process in a more ergonomic way.

Materials and methods

Determination of physical properties of young coconut fruits

Newly harvested young coconut fruits were obtained at random from a retail market in Selangor area. The fruits were taken from the orchards one day after harvesting. Hundreds of intact young coconuts from different varieties (*MATAG, Pandan* and *Gading*) were selected and measured to determine the diameter and height of each fruit using the Vernier Calliper. It was important to ensure that the fruits were free from physical damage beforehand. Each fruit was trimmed manually to determine the husk thickness. Knowledge on the physical properties of the coconut was substantial in designing the young coconut shaping machine. The height, diameter and size distributions of the fruits were analysed using a Minitab 16 software.

Machine design

The young coconut shaping machine comprises a main frame, bottom-up fruit holder, a shoulder trimming knife and a body trimming knife. *Figure 1* illustrates the main parts of the machine and its clamping components. The machine was driven by a single phase electric motor (Branco model) with variable rotational speed. A DC motor (Branco model) of 1 hp with maximum speed of 1,375 rpm was used. However, a range of 400 – 700 rpm was normally applied for trimming the fruits. In this case, 400 rpm is considered to be a minimum speed for trimming young coconuts. Basically, the longer the fruits being stored, the higher the rotational speed.

The design concept was to trim the vertically rotating fruit by using an inclined sharp knife at different angles to get the desired contour for the body and shoulder of the fruit. The cutting edge angles of shoulder and body blades ranged between 50 – 55° and 82 – 86° respectively. The most suitable angles of the feeding knives were determined according to the appearance and defect rate of the final trimmed fruit. For safety of the operator, the machine was also equipped with a sensor at the front cover which will cut off the electrical supply during loading and unloading of the fruit. A single operator was required to perform the trimming operation.

Prototype machine performance evaluation test

To evaluate the performance of the machine, *MATAG* was chosen as the test variety. A total of 200 newly harvested young *MATAG* coconut fruits were

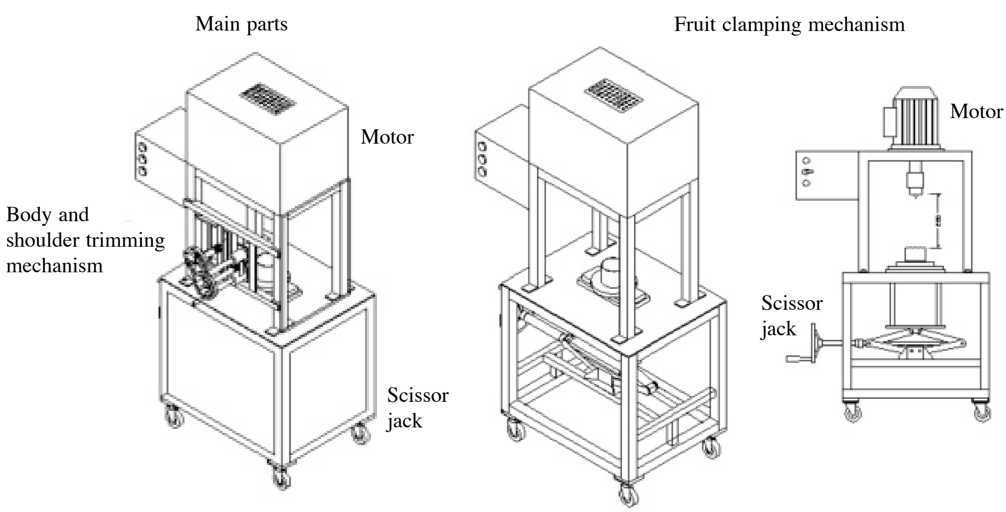

Figure 1. Prototype young coconut shaping machine

purchased from MARDI Hilir Perak. To evaluate the machine performance, 100 intact fruits, which have uniform shape and size, were selected. The fruits were trimmed continuously using the prototype young coconut shaping machine and the performance of the machine was evaluated. Manual trimming operation of the young coconut was also carried out simultaneously. Results from both methods were then evaluated and calculated in terms of production rate, product quality and optimum operating conditions. Production rate was calculated based on the finished produce capacity per hour whereas product quality was evaluated in terms of appearance of the final trimmed coconut. At the end of the trimming process, machine capacity was measured and percentage of defects was calculated using equation (1) and (2) which were developed by Jarimopas and Ruttanadat (2007).

$$\text{Machine capacity} = {}^{1}/\text{trimming time} \quad (1)$$

$$\text{Percentage of defects} = \frac{\text{(Number of broken product + unsuccessul trim product)}}{\text{Total trimmed fruit}} \quad (2)$$

Effect of storage on trimming time of young coconuts

A total of 60 newly harvested coconuts from *MATAG* variety were selected: 30 fruits were trimmed immediately after harvesting while the other 30 fruits were stored at ambient temperature (28 °C) for one week before they were trimmed using the prototype machine. The time taken for trimming the young coconuts with and without storage was compared. The speed of the prototype machine was set at 400 rpm and both samples used a new set of knife for trimming. The speed of 400 rpm was chosen because previous experiments done earlier had shown that this speed gave the finest trimming results. The results of trimming time were analysed using *t*-test (Minitab 16) to determine significance differences between the two samples.

Results and discussion

Physical properties of intact and trimmed young coconut fruits

The average height and diameter of intact fruit were 21.02 ± 1.36 cm and 17.32 ± 0.92 cm respectively (*Figure 2*). Both figures show normal distribution and about 80% of the fruits were medium size. The physical characteristics were the substantial data that determined the design of the fruit holder and trimming knife position. Therefore, the machine was basically designed to suit for medium size fruit.

Figure 3 present the statistics of the physical characteristics of trimmed young coconut with three different varieties (*MATAG*, *Pandan* and *Gading*). Obviously, *MATAG* was the largest and the most prominent in terms of circumference, diameter and overall husk thickness followed by *Pandan* and *Gading*. According to Hakim (2011), *MATAG* variety produces

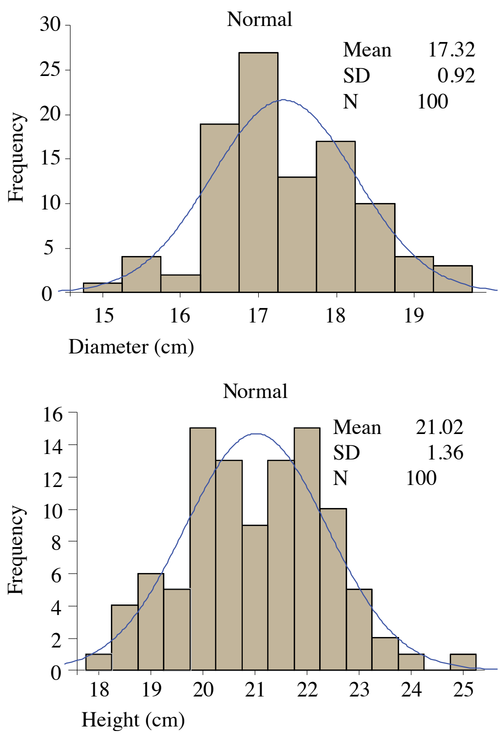

Figure 2. Histogram of intact young coconut fruit diameter and height distribution

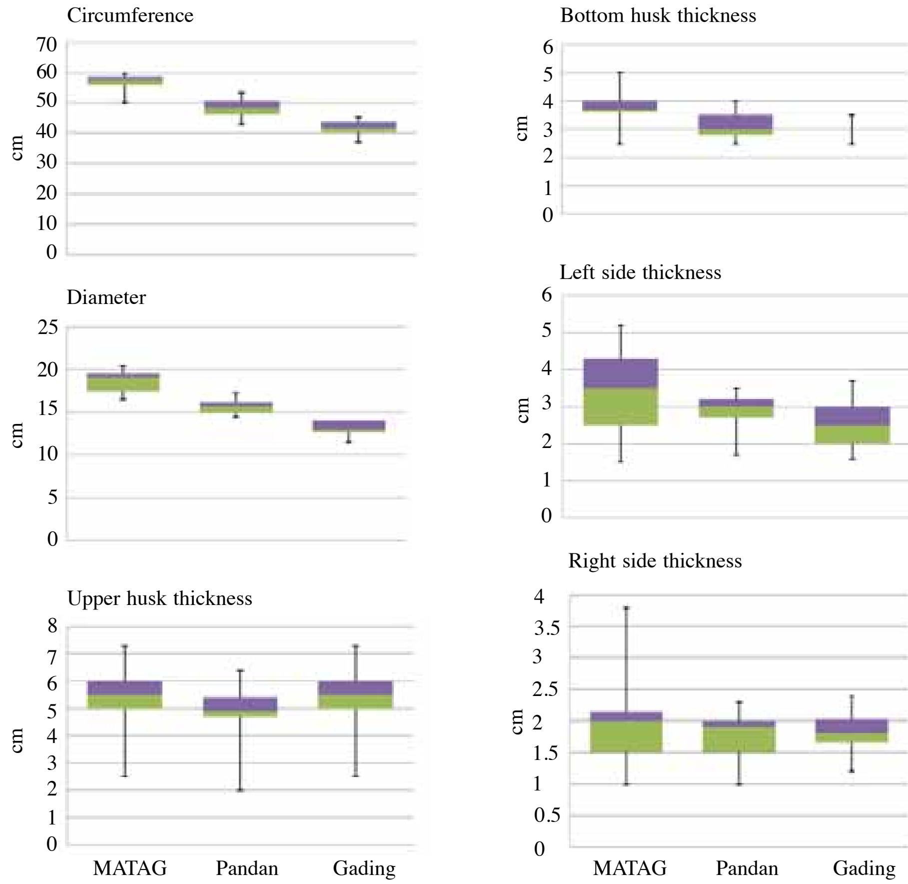

Figure 3. Boxplot of young coconut fruit physical characteristics of different varieties

fruits that are larger in size compared to *MAWA* and *Pandan* (*Figure 3*). The data shown in *Figure 3* also proved that *MATAG* variety had higher proportion of husk compared to *Pandan* and *Gading*. It was also found that the bigger size of intact fruit have higher thickness of husk.

Generally, the upper husk thickness was higher than the bottom husk thickness of all varieties. However, left and right sides husk thickness of the fruit vary and predominantly depended on the shape of the fruit. Wide variation in fruit shape and size exist within types and populations (Edward and Craig 2006). The data of the physical characteristic between intact and trimmed young coconut gave better understanding in optimising the trimming process. For instance, machine operator could allow deeper penetration of the feeding knife for certain variety such as *MATAG* where the husk is thick.

Machine operating procedures

Based on the physical properties data in *Figure 3*, the inclination angle of body and shoulder trimming knives were set according to the maximum and minimum size of *MATAG* variety. *Figures 4 – 5* clearly show the placement of the knives at different planes and the mechanism of trimming. The angle between knife plane to the horizontal plane of shoulder and body part were set at 30° and 37° respectively which remain to be unchanged. This set of angles (30° and 37°) was the best when holding the knives prior to trimming the fruits. In addition to that, the cutting edge angle gave significant

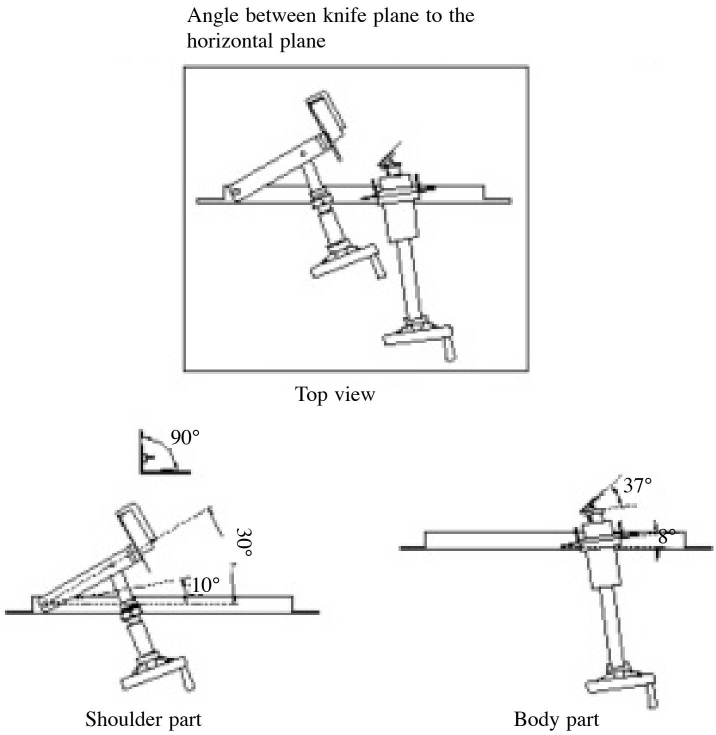

Figure 4. Top view of knife angle of the prototype machine

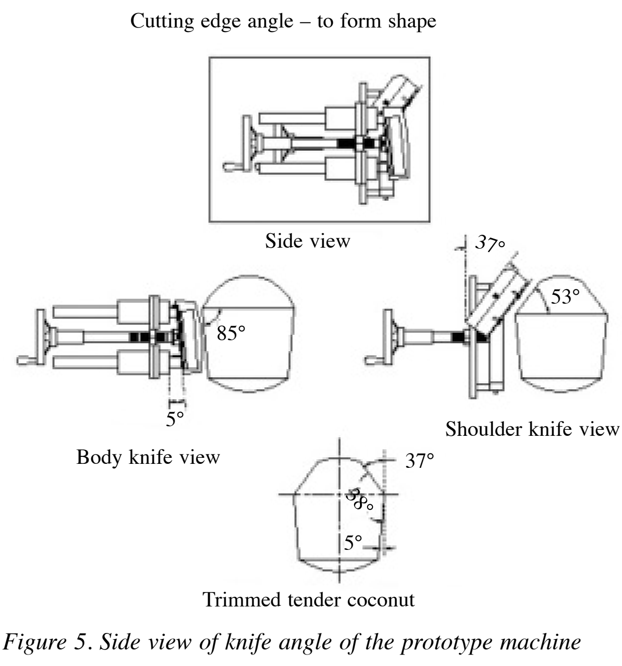

Figure 5. Side view of knife angle of the prototype machine

effect on trimming process thus many trials have been carried out in finding the right cutting edge angle for the shoulder and body knives. It was found that at 53° and 85° of cutting edge angles to *x*-axis for shoulder and body trimming respectively was the most optimum angles. This set of knives' angles also determined the shape of the final trimmed coconut.

The type of knives or blades used was hardened stainless steel which contains high proportion of carbon. According to Jarimopas and Kuson (2007), the stainless steel knife slowly penetrated through the husk of the rotating young coconut thus resulting in a circular opening at the top of the fruit. Therefore high carbon stainless steel blade was found to be durable and capable to undertake the trimming process.

The distance between top and bottom holder was designed according to the maximum height of *MATAG* variety since *MATAG* variety was chosen as the reference. The fruit holder also functioned as a guide and centre point that rotates the fruit about its vertical axis during the trimming process. In order to clamp and hold the fruit, a scissor jack was attached underneath the bottom holder. The scissor jack was used to bring the fruit up until it clamped firmly with the upper holder. After the fruit was held securely, the operator switched and pressed the button to start the operation. The trimming process was first done with shoulder part and then followed by body part of the fruit. The shoulder and body trimming station were placed next to each other to ease the operator. *Plate 1* shows the trimmed fruit after body and shoulder trimming process. When the trimming was completed, the machine stopped and the operator unloaded the trimmed fruit by lifting down the scissor jack. Finally, bottom-up cutting was performed manually using a very sharp knife to complete the trimming process.

Performance of the young coconut shaping machine on MATAG variety

Table 1 shows comparison of the performance of the prototype shaping machine with the manual method. Using the prototype machine, the unskilled worker managed to trim 389 nuts per day which was almost two times faster than manual trimming (using knife). Moreover, the final product produced by unskilled workers during manual trimming was not presentable due to uneven contour whereas the prototype machine managed to trim the fruit uniformly. As shown in *Plates 1* and *2*, the output from using the prototype machine had a hexagonal shape with less protruding fibre and there were no marked differences in terms of appearance compared to manual trimming. The prototype machine also reduced the risk of trimming by having a safety sensor attached to the front cover of the machine.

Figure 6 represents the performance of the prototype machine in terms of holding, trimming and manual bottom-up

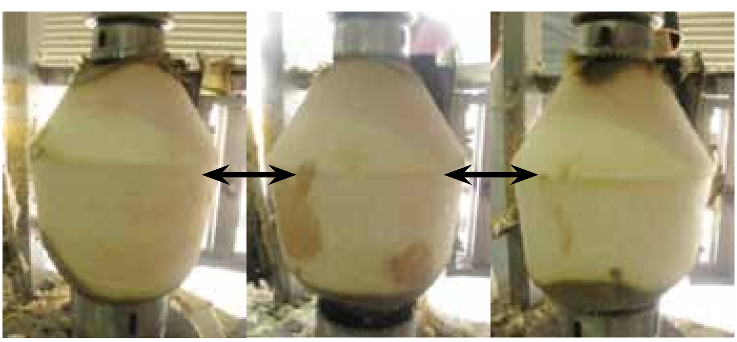

Plate 1. Uniform shape and contour of trimmed young coconut

Plate 2. Hexagonal shape of final trimmed young coconut

Table 1. Comparison between prototype and manual method by unskilled worker

Parameter	Prototype (manual knife feeding)	Manual trimming (using knife)
Trimming mechanism	Lathe trimming concept	Shearing and cutting
Processing rate (nuts/day/operator)	389 (excluding bottom-up cutting)	200 (excluding bottom-up cutting)
End product	Uniform in shape and contour	Shape and contour varies depending on operator's skills
Operation	Safe working condition	Risky operation

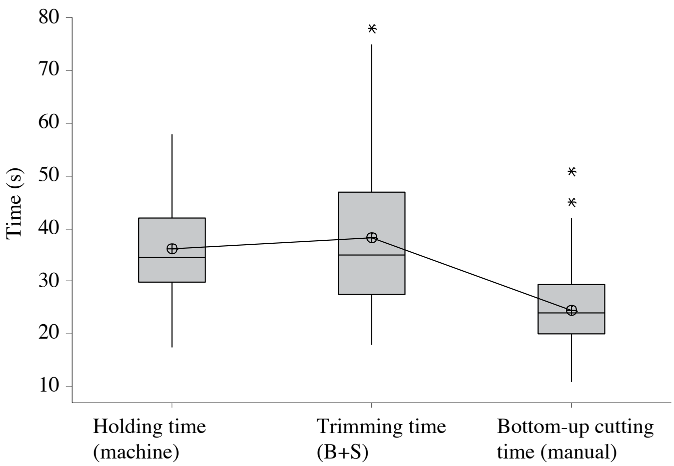

Figure 6. Side by side boxplot of prototype machine holding time, trimming time and manual bottom-up cutting time

cutting time. The average holding time was 36 s/nut. This was considered time consuming as the operator had to manually position and uplift the fruit. A total of 5% of the coconuts were damaged during the trimming process due to broken shell as a result of excessive trimming. The optimum operating conditions of the prototype machine were as follows: a) 400 rpm rotational speed; b) the trimming knives need to be changed or sharpened after 30 fruits had been trimmed; c) average shoulder and body trimming time (machine) was about 38 s/nut; d) average bottom-up cutting time (manual) was about 25 s/nut. The total processing rate of this prototype machine was 49 nuts per hour including the holding and trimming time. In comparison with the previous work done by Jarimopas and Ruttanadat (2007), their prototype machine could only trim 21 nuts per hour at 300 rpm rotation for newly harvested fruit. Nevertheless, the prototype of Jarimopas and Ruttanadat (2007) had different knife angles setting which suited the trimming mechanism of the prototype.

In *Table 2*, we could see the results of the t-test generated by Minitab 16. The mean trimming time for newly harvested fruit was 44 s whereas the mean for stored young coconut was 54 s. The difference was –9.17 meaning that the newly harvested fruit had shorter trimming time on average than the stored fruit. The t value for the difference in the two means was $t = -3.25$ which had a p value of 0.002. At a level of $p = 0.05$, this difference was considered significant because $0.002 < 0.05$. In other word, storage significantly affected the prototype trimming time to become longer. This

Table 2. Two-sample t-test of trimming time between newly harvested and aged young coconut

Two-sample T for newly harvested vs stored one week

	N	Mean	SD	SE Mean
Newly harvested	30	44.4	11.2	2.0
Stored one week	30	53.5	10.6	1.9

Difference = mu (newly harvested) – mu (stored one week)
Estimate for difference: –9.17
95% CI for difference: (–14.81, –3.52)
t-test of difference = 0 (vs not =): t-value = –3.25; p-value = 0.002; DF = 57

could be due to loss of moisture of young coconut husk during storage period hence making trimming process more difficult and consumed a lot of time. According to Yahia (2011), water loss from unpeeled young coconut is about 3% per week in ambient condition. After peeling and wrapping with PVC film, the white husk appears shrivelled after 4.5% weight loss.

Conclusion

The prototype machine was designed and tested for trimming body and shoulders of young coconut fruit. The machine performance test indicated a trimming (body and shoulder) capacity of about 95 fruits/h with total holding and trimming process of about 49 fruits/h. Grading and sorting of the fruits were important aspects prior to the trimming process. With an acceptable defect rate, medium size *MATAG* variety fruit was satisfactorily suited to this prototype. The cutting edge angles of the shoulder and body knives that were set (53 and 85) respectively have proven to generate smooth trimming with less protruding fibres on the final product. The optimal operating parameter of the machine was suitable for newly harvested fruit at a rotational speed of 400 rpm. The objective of this study has been achieved as the prototype machine could perform major function of body and shoulder trimming safely. However, further improvement on manual knife feeding and fruit clamping mechanisms need to be carried out to reduce holding and trimming time significantly. The results presented will be helpful in upgrading and improving the design.

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Abstrak

Projek ini telah dijalankan untuk mereka bentuk dan membangunkan sebuah mesin pembentuk kelapa muda. Tujuan utama reka bentuk mesin ini adalah untuk merepang dan membuang kebanyakan kulit luar kelapa muda yang berwarna hijau untuk menghasilkan bentuk kelapa muda (heksagon) yang lebih menarik serta mudah dibelah. Mesin prototaip berdasarkan mekanisme mesin larik yang terdiri daripada sepasang pisau dan pemegang atas dan bawah untuk mengapit buah kelapa muda. Semasa operasi dijalankan, buah kelapa muda diletakkan secara menegak pada pemegang dan dikapit sebelum proses pembentukan bermula. Apabila buah kelapa muda berputar, pekerja perlulah mengawal kedalaman pisau pembentuk secara manual sehingga kebanyakan kulit hijau dipotong. Kelajuan putaran buah juga boleh diselaraskan sewajarnya. Mesin prototaip ini berupaya untuk membentuk 95 biji kelapa muda sejam apabila kelajuan putaran mesin dihadkan pada 400 rpm. Kerosakan buah adalah sekitar 5% dan pisau perlu diganti selepas setiap 30 biji buah kelapa dibentuk.

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