Design and Evaluation of an Improved Aluminium Harvesting Pole (Hi-Reach) for Tall Palm Harvesting

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ABSTRACT

A new harvesting pole (Hi-Reach), specifically designed for tall palm trees (>12 m high), was developed and tested. It comprised three sections, namely, the basal, middle and top sections, which were joined through a telescopic method to make up a total length of 15 m. The pole was oval with cross-sectional diameters of the major and minor axes of 44 mm x 41 mm, 40 mm x 35.5 mm and 35.5 mm x 29 mm for the basal, middle and top sections, respectively. With section lengths of 3 m and 6 m, it was possible to have three combinations for the total length of 15 m. The combinations of length are denoted as Pole X (3 m + 6 m + 6 m), Pole Y (6 m + 6 m + 3 m) and Pole Z (6 m + 3 m + 6 m).

A physical test was carried out with the objective of investigating the effects of the design parameters (cross-sectional shape, dimension and combination of length) on the weight, deflection, distance of centre of gravity from the base (cog) and lifting moment. The test carried out showed that Pole X exhibited the least weight and lifting moment, and the shortest distance of cog, while Pole Y exhibited the opposite characteristics. The weight, lifting moment and distance of cog of Pole X were 7 kg, 56.35 kg-m and 8.05 m, respectively. In comparison, the parameters for Pole Y were 7.5 kg, 61.43 kg-m and 8.19 m.

The poles were sent to over 20 commercial plantations in Peninsular Malaysia for field evaluation. The results of the trial showed that Pole X produced the highest harvesting productivity (146 FFB day⁻¹), while Poles Y and Z only harvested 123 FFB day⁻¹ and 102 FFB day⁻¹, respectively. From these results, it clearly indicated that poles with the characteristics of lightweight, shorter distance of cog from the base and lower lifting moment (in this case, Pole X) gave better productivity than poles with the opposite characteristics.

This study revealed that harvesting productivity was significantly influenced by the pole characteristics, viz. weight, deflection, distance of cog and lifting moment. However, these characteristics are very much influenced by the pole design parameters such as its cross-sectional shape, cross-sectional dimensions and combination of lengths.

It was concluded that Pole X (3 m + 6 m + 6 m) was the best combination as proven through the physical test and field trials.

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ABSTRAK

Galah penuai baru (Hi-Reach), direkabentuk khusus untuk pokok tinggi (ketinggian >12 m) telah dibangunkan dan diuji. Ia merangkumi tiga seksyen dikenali sebagai seksyen asas, tengah dan hujung, yang disambung secara teleskopik bagi menjadikan jumlah panjang 15 m. Galah ini berbentuk oval dengan diameter keratan rentas untuk paksi utama dan paksi kecil masing-masing adalah 44 mm x 41 mm, 40 mm x 35.5 mm dan 35.5 mm x 29 mm untuk seksyen asas, tengah dan hujung. Dengan panjang seksyen 3 m dan 6 m, tiga kombinasi sambungan dapat dibentuk bagi jumlah panjang 15 m. Kombinasi-kombinasi seksyen ini dinamakan sebagai Galah X (3 m + 6 m + 6 m), Galah Y (6 m + 6 m + 3 m) dan Galah Z (6 m + 3 m + 6 m).

Ujian fizikal telah dijalankan bertujuan untuk mengenalpasti kesan parameter rekabentuk (bentuk keratan rentas, dimensi dan kombinasi panjang) ke atas berat, lenturan, jarak pusat graviti dan momen mengangkat. Ujian yang dijalankan menunjukkan Galah X mempunyai berat, momen mengangkat dan jarak pusat graviti yang paling minimum, manakala Galah Y menghasilkan ciri-ciri yang berlawanan. Berat, daya mengangkat dan jarak pusat graviti bagi Galah X masing-masing adalah 7 kg, 56.35 kg-m dan 8.05 m. Sebagai perbandingan, pa-
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increased the cost of production (Tan Book Thiam, 1990; Stanners, 1992a,b).

Having realized these problems, PORIM, in 1986 introduced telescopic aluminium poles (popularly known as the Zirafah) to substitute for the wooden and bamboo poles (Abdul Halim Hassan et al., 1988). The Zirafah is oval in shape and available in two sections, namely, a basic (the larger diameter) and extension poles. The dimensions of the basic and extension poles for the major and minor axes are 45 mm x 35 mm and 39.5 mm x 29.5 mm, respectively. The ratios of diameters of the major to minor axes are 1.28 and 1.34 for the basic and extension poles, respectively. They are available in two lengths, viz. 6 m and 9 m.

Trials carried out showed that the Zirafah was suitable for palms of 12 m or lower but could not perform well on palms above 12 m as proven from field trials carried out in tall palm areas. The productivity per harvester per day was low because the harvester faced difficulty in lifting the pole and moving from one palm to another. These problems were due to the high deflection of the pole, particularly on its minor axis during lifting. This resulted from the high diameter ratio of major to minor axes (1.28 and 1.34 for the basic and extension poles, respectively). Hence, the pole tended to twist during lifting leading to a higher deflection. This made the pole difficult to handle and easy to fall.

This paper highlights the design of an improved aluminum pole, the physical test, field trials carried out in commercial estates, and the results of the tests and field trials. Some recommendations are also discussed.

INTRODUCTION

Previously, fresh fruit bunches (FFB) of tall palm trees were harvested using a sickle attached to either a long wooden or bamboo pole. This device was inconvenient in that the pole length was fixed, making it difficult to harvest FFB from palms of varying heights. The heavy weight of the wooden or bamboo poles made the handling of the harvesting device inefficient and clumsy. Furthermore, the durability of the pole was poor. Dry bamboo or wooden poles tended to break when a slight transverse/lateral force is applied along the longitudinal axis. The poles were not stiff enough, an essential factor in a harvesting pole. Scarcity in getting the desired lengths of bamboo or wood to harvest very tall palms (> 12 m high) and the problems mentioned earlier made them inappropriate for commercial use (Adetan and Adekoya, 1995; Foo See Yak, 1981; Veldhuis, 1983). These disadvantages generally decreased the productivity of the harvester and increased the cost of production (Tan Book Thiam, 1990; Stanners, 1992a,b).

OBJECTIVES

The objectives of the study were:

a) to design a long pole with lower weight, lower deflection, lower lifting moment and shorter distance of the cocf from the base;

b) to investigate the effects of the design parameters (cross-sectional shape, cross-sectional dimensions and combination of lengths) on the pole weight, cocf from the base, deflection and lifting moment; and

c) to evaluate their performance in commercial plantations.
POLE’S DESIGN

Design Considerations

The following were the main criteria considered in the design of the harvesting pole:

- a) lightweight - for easy handling;
- b) high stiffness - to reduce deflection especially during lifting;
- c) rustproof - to last longer;
- d) hard - to prevent denting;
- e) ergonomic - for comfortable hand gripping; and
- f) durability.

Trials carried out by Razak et al. (1998) had proven that a pole with lower deflection and lifting moment is easier to handle, and therefore, more FFB can be harvested. To lower the deflection and moment, one should consider the design parameters that include the cross-sectional diameter and shape of the pole, as well as the combination of lengths. To reduce the lifting moment, the config should be brought towards the bottom of the pole. This can be done by either increasing the cross-sectional diameter or shortening the length of the basal pole.

The Design

Three parameters were taken into consideration in the design. They were the cross-sectional shape, cross-sectional diameters and combination of lengths.

The designed harvesting pole was an improvement of the first model (the Zirafah, Figure 1). The reason for choosing an oval shape was to increase the contact surface area for better hand gripping. The Zirafah had a wall thickness of 1.3 mm, but was a bit thicker (2 mm) on the minor axis with the aim of increasing the pole’s stiffness, thus preventing the pole from buckling. This model can be done by either increasing the cross-sectional diameter or shortening the length of the basal pole.

The Combinations

The selected lengths of the pole were 3 m and 6 m. With these lengths, three combinations could be established, viz. 3 m + 6 m + 6 m, 6 m + 6 m + 3 m and 6 m + 3 m + 6 m, to make up a total length of 15 m. The poles were fastened together by a specially designed clamp (Figure 3), which telescoped the smaller sections into the bigger sections.

The Clamp

The clamp (Figure 3) consisted of two parts, one part permanently fixed to the bottom...
TABLE 1. DIMENSIONS OF THE ZIRAFAH AND HI-REACH

| Section | Zirafah | | | Hi-Reach | | |
|---------|---------|-----------------|---------|-----------------|---------|
|         | Major   | Minor           | Ratio   | Major           | Minor   |
|         | axis    | axis            | major/minor | axis            | axis    | major/minor |
| Basal   | 45      | 35              | 1.3     | 44              | 41      | 1.07       |
| Middle  | 39.5    | 29.5            | 1.3     | 40              | 35.5    | 1.12       |
| Top     | 35.5    | 29              |         | 35.5            | 29      | 1.22       |

Sources: adapted from Abdul Halim Hassan et al. (1988); Abdul Razak Jelani and Ahmad (2000).
section, while the top part was adjustable. A lever was used to tighten the top section firmly inside the top clamp. Using this clamp, a harvester no longer had to use a spanner for adjusting the pole length. This saved time. Figure 4 illustrates the cross-sectional configurations for each section of the poles and the clamps.

MATERIALS AND METHODS

Three combinations of length were prepared for testing, denoted as Pole X (3 m + 6 m + 6 m), Pole Y (6 m + 6 m + 3 m) and Pole Z (6 m + 3 m + 6 m), making up a total length of 15 m.

Determination of Centre of Gravity (cofg), Deflection and Weight of Poles

The cofg was the centre of weight of the pole, while deflection was the deflection of pole when it is hung at cofg (when both ends of the pole are free from the ground, Figure 5). The lifting moment was defined as the product of the total weight and the distance of cofg from the base of the pole.

Test Procedures

The test procedures were similar to those carried out by Razak et al. (1998). The same experimental test rig was used to carry out the physical tests. In the experiment, the test pole was lifted by a cable (somewhere in the middle) until both of its ends were just lifted off the ground as shown in Figure 5. The place where the cable was positioned at the balanced position was the cofg of the pole. The distance of this point from ground level was measured to indicate its maximum deflection under its dead weight. The weight of the pole was recorded by a spring balance. The tests were made with and without a sickle attached at the end of the poles.

Field Trials

A series of field trials were carried out in more than 20 commercial plantations in Peninsular Malaysia to assess the performance in terms of productivity and durability. The estates chosen for the trial were those having palm trees more than 12 m high.
Trial Procedures

In the trials, the present harvesting systems practiced in the particular plantations were maintained. Two workers were involved where one worker did the cutting while the other did the stacking of fronds, collecting loose fruits and carrying the FFB to the roadside. Each harvester used the same brand of harvesting sickle to avoid variation in the handling.

Only harvesters with comparatively good skills were involved in the field trials. They were given a week to be familiar with their poles before data was collected. Each harvester was asked to use a pole for one month, after which, they exchanged poles until they finished using all the types of poles.

A time and motion study (TMS) was made to record the times taken to carry out all the activities in the harvesting operation (lifting the pole, carrying upright, cutting fronds and FFB). It was done on each pole over 1 hr of harvesting. The number of FFB cut per day was recorded as well. Any incidents on the pole, such as bending and breakage, were also noted.

RESULTS AND DISCUSSIONS

Determination of Centre of Gravity (cofg), Deflection and Weight

The weight, deflection, cfg and lifting moment of the tested poles are shown in Figures 6 to 9.

Pole X was found to have the lowest weight (7 kg) compared to Poles Y and Z that were 7.5 kg and 7.25 kg, respectively. For deflection at the point of cfg, Pole Y produced the least (128 cm) compared to Poles X and Z with 145 cm and 141 cm, respectively. In terms of the distance of cfg from the base, Pole Y had the longest distance (8.19 m), while Pole X had the shortest (8.05 m). The lifting moment of the Pole Z was the highest (61.43 kg-m) compared to Poles X and Z that produced only 56.35 kg-m and 58.51 kg-m, respectively.

The experiment carried out showed that Pole X was the best combination as it produced the shortest distance of cfg and lifting moment, as well as the least weight. However, it produced the highest deflection. Deflection and lifting moment are two important parameters, but in most cases, they oppose each other, i.e deflection...
Centre gravity of pole
(with 1 kg sickle attached to the upper section)

<table>
<thead>
<tr>
<th>Model</th>
<th>Pole Z</th>
<th>Pole Y</th>
<th>Pole X</th>
<th>Zirafah</th>
</tr>
</thead>
<tbody>
<tr>
<td>cofg (m)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 9. Comparison of the distance of cofg from the base between Hi-Reach and Zirafah.

is inversely proportional to the lifting moment. For Pole X, the distance of cofg was the shortest as the length of the basal pole was short (3 m), and the distribution of weight was brought towards the base of pole. However, the pole became less stiff hence resulting in a higher deflection.

In general, the results of the test were in line with the finding by Razak et al. (1998) that the pole physical characteristics had a significant effect on the parameters studied (cofg, deflection, weight and lifting moment).

Pole Performance

**Time and motion study (TMS).** Table 2 shows the TMS taken during the trial. The data for each activity in the harvesting operation collected from the six plantations were averaged to see the effect of the pole’s characteristics on the time taken to carry out these activities.

In lifting, Pole X required the shortest time (12 s) compared to the others due to its lightweight (7 kg), lowest lifting moment (56.35 kg-m) and the shortest distance of cofg (8.05 m). The combination of these factors was found to make the lifting faster.

A similar trend was found in the cutting, wherein Pole X required only 16 s and 20 s to cut a frond and fruit bunch respectively. Overall, Pole Z was the most difficult to handle as it took the longest time to complete a harvesting cycle. One of the main reasons was that the pole tended to vibrate during lifting making it difficult to handle.

The experiments conducted clearly showed Pole X to be the best combination for the time taken to complete a harvesting cycle. It took only 62 s, whereas Poles Y and Z took 86 s and 119 s, respectively.

**Productivity.** Table 3 shows the average harvesting productivity per day by the harvesters in the six estates.

Overall, Pole X gave the highest productivity (146 FFB day⁻¹), followed by Poles Y and Z with 123 and 102 FFB day⁻¹, respectively. This was in line with the results of TMS in Table 2 where Pole X required the least time to complete a harvesting cycle over the other poles. Although Pole Y had the longest distance of cofg (8.19 m) and the highest lifting moment (61.43 kg-m), its lower deflection (128 cm) made it easy to be lifted, resulting in a better performance than Pole Z. However, its heavy weight made it difficult to carry upright from one palm to another. It was clearly shown in TMS that it required 30 s to be carried, slowing down the harvester’s movement in the field. As a consequence, the overall productivity was low.

For Pole Z, its combination of (6 m + 3 m + 6 m) with a short section in the middle and long sections at the ends caused the pole to vibrate during lifting, thus making it difficult to handle.

**Long-term Field Trial**

Since Pole X was the best combination for harvesting productivity, it was sent to two plantations for a long-term field trial. Two plantations were involved, i.e. Estate Pekebun Kecil (ESPEK) Bera and Persatuan Peladang Negeri Johor (PPNJ) Bukit Bujang in Segamat, Johor. Figures 10 and 11 show the harvesting productivity by the harvesters. The harvesting productivity ranged from 90 to 170 FFB day⁻¹ and 100 to 170 FFB day⁻¹ for PPNJ Bukit Bujang and ESPEK Bera, respectively. However, the productivity depended very much on the cropping, field topography as well as the harvester’s skill. The poles lasted about eight to 12 months depending on the method of use.

Observations made showed that the life of the pole can be prolonged if proper handling and good care are taken by the harvester. Among the
factors that affect the durability of the pole are:

a) fronds falling or hitting the pole; and,
b) pole falling down.

Both the factors cause the pole to dent and bend and finally break. However, a skilled harvester does not allow his pole to fall. He normally carries it upright when moving from one palm to another. This obviously prolongs the life of the pole.

**ECONOMIC ANALYSIS**

Cost effectiveness is measured in terms of the bunches harvested per man day as a ratio of the cost of the tool. The purchase price of the pole was RM 200. Taking an average productivity of 120 FFB day⁻¹, 23 days working day a month, therefore:

\[
\text{Cost effectiveness} = \frac{\text{RM 200}}{8 \text{ months} \times 23 \text{ days} \times 120} = \text{RM 0.01/bunch}
\]

### Table 2. Time and Motion Study of the Poles Tested

<table>
<thead>
<tr>
<th>Activity</th>
<th>Pole X</th>
<th>Pole Y</th>
<th>Pole Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>To lift the pole up (s lift⁻¹)</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>To carry up-right (s carry⁻¹)</td>
<td>14</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>To cut frond (s frond⁻¹)</td>
<td>16</td>
<td>19</td>
<td>32</td>
</tr>
<tr>
<td>To cut FFB (s FFB⁻¹)</td>
<td>20</td>
<td>23</td>
<td>41</td>
</tr>
<tr>
<td>Total time taken (s)</td>
<td>62</td>
<td>86</td>
<td>119</td>
</tr>
</tbody>
</table>

Note: average of four harvesters for each estate.

### Table 3. Daily Average Productivity (FFB day⁻¹)

<table>
<thead>
<tr>
<th>Estate</th>
<th>Pole X</th>
<th>Pole Y</th>
<th>Pole Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>127</td>
<td>101</td>
<td>85</td>
</tr>
<tr>
<td>B</td>
<td>117</td>
<td>94</td>
<td>74</td>
</tr>
<tr>
<td>C</td>
<td>157</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>D</td>
<td>107</td>
<td>76</td>
<td>58</td>
</tr>
<tr>
<td>E</td>
<td>209</td>
<td>193</td>
<td>185</td>
</tr>
<tr>
<td>F</td>
<td>162</td>
<td>145</td>
<td>110</td>
</tr>
<tr>
<td>Average</td>
<td>146</td>
<td>123</td>
<td>102</td>
</tr>
</tbody>
</table>

Note: average of four harvesters for each estate.

![Graph 1](image1.png)  
**Figure 10.** Harvesting productivity of Hi-Reach at ESPEK Bera.

![Graph 2](image2.png)  
**Figure 11.** Harvesting productivity of Hi-Reach at PPNJ Bukit Bujang.
DISCUSSION

Factors such as the combination of lengths, cross-sectional shape and cross-sectional dimensions are the key aspects to improve the effectiveness of the pole. Poles with a short section at the bottom were proven to be good, as they could be easily handled. This was as a result of reduction in weight as well as shorter distance of cofg to the bottom of the pole.

The oval shape of the pole increased the contact surface area for the hands to grip, thus preventing the pole from turning especially during lifting. The wider surface area also allowed the hand to grip it more comfortably.

At the same time, the cross-sectional dimensions of the pole influenced the total weight, deflection and lifting moment. Realizing these, the dimensions of the pole should be designed in such way so as to minimize the deflection and lifting moment as well as reduce the weight of the pole. But in most cases, the lifting moment is inversely proportional to deflection. Therefore, the cross-sectional dimensions should be designed in such way so as to tolerate this problem.

It was proven that the Hi-Reach is suitable for harvesting tall palm. Using this pole, tall palms that could not be harvested before can now be harvested. Pole X which had the combination of lengths 3 m + 6 m + 6 m was the best in terms of ease of handling and showed the highest productivity. This pole had the lowest weight, the shortest distance of cofg and the lowest lifting moment, making it easy to handle. The average productivity per worker was 146 bunches day\(^{-1}\) or 2 to 2.5 ha day\(^{-1}\). The working hours of the harvester could be lengthened to increase this daily productivity. The pole lasted six to 12 months under normal use.

Over the period of testing, it was found that worker attitude is an important factor in the acceptance of any new tool introduced, followed by commitment from the management. This was proven through experience in some estates where the acceptance of this new pole was very encouraging. Harvesters who are committed and responsible take better care of the poles and prolong the live span of the poles.

CONCLUSION

The results of the study show that:

- design factors, i.e. the combination of lengths, cross-sectional shapes and cross-sectional dimensions of the pole, significantly affected the physical characteristics of the pole (weight, deflection, distance of cofg and lifting moment);
- poles with lower weight, lower deflection, shorter distance of cofg and lower lifting moment were easier to handle. As a result, the harvesting productivity increased;
- Pole X required the least time to complete a harvesting cycle (lifting, carrying upright, cutting a frond and cutting a FFB). It took only 62 s compared to Poles Y and Z, which required 86 and 119 s, respectively. This was due to its light weight, short distance of cofg and low lifting moment; and
- Pole X also produced the highest productivity (146 FFB day\(^{-1}\)) compared to Poles Y and Z which produced 123 and 102 FFB day\(^{-1}\), respectively.

The Hi-Reach pole increased the efficiency of harvesting. Workers could harvest more fruits as the taller palms could be reached. As the pole was light, back strain was no longer reported. Its telescopic feature enabled the workers to harvest palms of different heights.

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