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DEVELOPMENT AND EVALUATION OF A NEW GENERATION OIL PALM MOTORISED CUTTER (*Cantas Evo*)

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ABSTRACT

MPOB has introduced an oil palm motorised cutter called Cantas *for palms below 5 m harvesting height.* Cantas *could double up harvesting output compared to manual harvesting. However, several weaknesses viz. frequent breakdown, heavy and high vibration make it less favourable to users. This article describes the development, laboratory and field tests of the new generation* Cantas *called* Cantas Evo. *Results showed that* Cantas Evo *passed all the required laboratory tests. The weight and vibration of* Cantas Evo *are respectively 31% and 95% lower than the previous version of* Cantas. Cantas Evo *is able to reach 7 m harvesting height. Field trial conducted in Kuala Muda Estate in Kedah, Malaysia revealed that the repair cost was reduced by 90%, a saving of about RM 3000 per machine per year. With the good quality and performance,* Cantas Evo *is effective for palms of up to 7 m harvesting height. As for the economics, based on the machine cost of RM 3800 per unit, the harvesting cost comes to about RM 21.24 t^{-1} fresh fruit bunches (FFB), with the cost-effectiveness of RM 1.18 t^{-1} FFB.*

Keywords: *Cantas Evo*, oil palm motorised cutter, harvesting tool.

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INTRODUCTION

Mechanisation is a pertinent approach to improve workers' productivity which is ultimately aimed at reducing workers requirement in estates. Malaysian Palm Oil Board (MPOB) has made significant breakthroughs in developing technologies of which some have been successfully commercialised such as aluminium harvesting pole (*Zirafah* and *Hi-Reach*), motorised cutter (*Ckat* and *Cantas*), mechanical loader (*Grabber*), fresh fruit bunches (FFB) infield transporters (*Beluga* and *Rhyno*) and loose fruit picker for loose fruits collection.

The total oil palm planted area in Malaysia (as of December 2015) was about 5.64 million hectares, contributing gross income to the country of about RM 66 billion a year. It is a fact that at present the industry is really dependent on foreign labour to carry out field operations. Latest statistics shows that there are about 340 283 foreign workers in this industry which accounts for about 77.8% of the total field workers in the plantation sector (MPOB, 2016). The issue has become very critical because there are cases in estates where the harvesting round has to be extended to about once in 20 to 25 days due to insufficient workers in the plantations. There are also cases where the estates have to do early replanting even when the palms are still producing good yield because they do not have workers who can harvest tall palms despite offer of high pay. A more serious problem is that more than 90% of the

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harvesting operation, the core activity in the oil palm plantation, is carried out by foreign workers. This is a very critical issue that needs to be seriously addressed. Various ways and means have to be identified to deal with the issue, and one way is through mechanisation.

Oil Palm Mechanisation

Efforts to increase workers' productivity by adopting new methods and technologies are being implemented and enhanced in the industry. There are three elements that contribute significantly to productivity of the workers, *i.e.* (i) tool, (ii) work system, and (iii) labour that need to be well synergised in order to achieve optimum productivity. With the right tool, effective work system and trained operators, maximum output can then be derived.

Mechanised Harvesting of FFB

Efficient harvesting can be achieved by using efficient harvesting tools and sufficient harvesters to cater to harvesting rounds of the recommended 10 to 12 days' interval. Difficulty in getting skilled harvesters has been a real issue that demands effective solutions. Manual harvesting (using a sickle or chisel) can only produce an average of 1 t FFB per worker per day (Azman *et al*., 2015). Estates are now looking for more efficient harvesting tools which can increase productivity and ultimately reduce the number of workers. The harvesting productivity needs to be increased to about 4 t FFB per worker per day to reduce labour requirement significantly.

Works in developing harvesting technologies had been initiated since 1990s when a light-weight aluminium harvesting pole known as *Zirafah* was introduced (Abdul Halim *et al*., 1988; Abdul Razak *et al*., 1998a) to replace the cumbersome bamboo pole. Later, Abdul Razak *et al*. (2002) introduced the improved version (called *Hi-Reach* pole) which was lighter and stiffer, for better handling in tall palm harvesting. Currently, there are several brands of harvesting poles of alloy or graphite material, with two or three telescopic sections to suit the required harvesting heights.

Mohd Ramdhan and Abd Rahim (2014) reported the trial of a one-man operated mechanical harvester that involved cutting, loading and transporting the FFB from the palms to the roadside. The machine could reach palms up to 11 m height. It was a tracked type machine where all the deployments were hydraulically controlled. Trial conducted in several estates showed that the productivity of the machine was about 200 – 250 FFB per day with the operational cost of about RM 52.44 t^{-1} FFB (including depreciation, fuel, repair, and maintenance and labour costs). The cost of the machine was RM 220 000 per unit.

Oil Palm Motorised Cutter (*Cantas*)

One of MPOB's technologies that has been well accepted is the oil palm motorised cutter (called *Cantas*) that was introduced in 2007. Cantas is suitable for harvesting FFB from palms up to 5 m harvesting height and was able to increase harvesting productivity by more than double. This could increase the take-home pay of the harvester and reducing the number of harvesters which is currently dominated by foreign workers. *Cantas* benefits the smallholder, individual harvester, contractor and estate in terms of increasing productivity and income, and reducing workers and operational costs.

Cantas is a motorised cutter specifically designed for harvesting FFB and cutting fronds. It is powered by a small petrol engine and utilises either a specially designed C-sickle or chisel as the cutting knife. MPOB is the technology owner with patents filed in Malaysia, Indonesia, Thailand, Brazil, Costa Rica and Colombia. The use of such technology will help the estates and the country to reduce foreign labour. The suitability of *Cantas* in relation to harvesting height is shown in *Table 1*. *Cantas* is currently manufactured by several local and international companies. *Table 2* shows the average performance of *Cantas* against manual harvesting tool based on data collected in 21 estates (Abdul Razak *et al*., 2013).

TABLE 1. VERSIONS OF *Cantas* AND ITS SPECIFICATIONS

Version	Length (m)	Reach (m)	Cutting knife	Weight (kg)	Remarks
Ckat	2.0	2.0	Chisel	5.0	Short palms (<1.5 m)
Cantas3	2.0	2.0	C-sickle	5.0	1.5 – 2.4 m
Cantas5	3.6	4.5	C-sickle	7.2	2.4 – 4.5 m
Cantas7	5.0	7.0	C-sickle	7.6	4.5 – 7.0 m

Problem Statement

Cantas has been chosen as one of the project under the Malaysian Economic Transformation Programme (ETP) as a means to increase workers' productivity and reduce requirement of workers in oil palm plantation (Economic Transformation Programme Annual Report, 2012). Since its introduction, MPOB received both positive and negative feedbacks from the users. On the positive side, majority agreed that *Cantas* can help to speed up harvesting operation, increase harvesting productivity and reduce workers requirement. On the other hand, there are

TABLE 2. PERFORMANCE OF *Cantas vs.* CONVENTIONAL HARVESTING USING POLE AND SICKLE IN ESTATES

	Cantas	Manual	Difference
Harvesting productivity (t FFB per day per tool)	6.75	3.4	+3.35 (+99%)
Workers productivity (t FFB per worker per tool)	2.61	1.7	+0.91 (+55%)
Labour to land ratio	1:32	1:20	+12 (+55%)

Note: FFB - fresh fruit bunches.

also weaknesses that need serious attention mainly on the durability and ergonomic of the machine. The weaknesses are: (i) frequent breakdown especially the cutting head, (ii) heavy, and (iii) high vibration. All these issues had caused *Cantas* to be less favourable, causing decline in sales since 2012. Solving these issues can apparently increase users' satisfaction hence increasing the uptake. Cause and effect analysis was made using 5W 1H concept which is explained in *Table 3*.

This article highlights the improvements that have been carried out as well as laboratory and field tests of the new generation *Cantas* know as *Cantas Evo*. These improvements were mainly aimed at increasing cost lost-effectiveness and profit to the plantations using *Cantas*.

OBJECTIVES

The objective of this project was to develop a new generation *Cantas* with the following aims:

- high quality and durable (less breakdown) with the repair cost of below RM 1.00 t^{-1} FFB;
- generating vibration of below 2.5 m s^{-2} according to the ISO 5349 Standard; and
- having the specific weight of below 1.5 kg m^{-1}.

Table 4 shows the gap analysis between the current standing and the target requirements.

MATERIALS AND METHODS

Design

The new design of the prototype is focussed at solving the three main issues *i.e.* frequent breakdown especially the cutting head, heavy weight and high vibration. The specifications of the previous version of *Cantas* and the design of the new version are shown in *Figure 1*. Four main components were involved in the improvements *i.e.* the cutting head, main pole, shaft guider and engine.

Improvement of the Cutting Head and Vibration Reduction

Cutting head design. The cutting head must be strong and robust to overcome the toughness of the oil palm fronds and fruit stalks and to withstand the rough handling by the harvesters (Abdul Razak *et al*., 1998b). It has been calculated that the revolution of the cutting mechanism (gears and connecting-rod) is about one million revolutions a day which

TABLE 3. 5W 1H ANALYSIS ON *Cantas* ISSUES

What?	Feedback from users stated that the breakdown frequency was very high. It was also difficult to handle during harvesting. These issues disrupted the harvesting operation as the workers have to stop harvesting many times in a day to fix the problems and to have some rest. The improvement is very necessary to increase durability and ergonomics of the machine.
Where?	The occurrences were in the oil palm field.
When?	It happened during harvesting and pruning activities.
Who?	The persons involved are the harvesters, MPOB and the manufacturers of *Cantas*.
Why?	Feedback from the users have disclosed three main root causes: a. Frequent breakdown, mainly the cutting head. This disrupts the smoothness of the harvesting work and contributes to high repair cost. b. Heavy machine which takes out workers' stamina. c. High vibration of the machine affects workers' stamina and health *i.e.* back strain and exposes the workers to hand arm vibration syndrome (HAVS).
How much?	The weight of the machine was between 8.0 to 9.0 kg. The repair cost was about RM 4.03 t^{-1} FFB. The vibration was greater than 10 m s^{-2} which may trigger adverse effect to the operators.
How?	a. Improving the durability of cutting head - this can be done by improving the design of cutting head including the selection of right material for special purposes, *i.e.* right material for component to stand high friction, *etc.* b. Reducing the weight – this can be done by reducing weight of several components.

TABLE 4. GAP ANALYSIS

Objective	Current standing	Target	% GAP
Improve durability	Repair cost at RM4.03 t^{-1} FFB	< RM 1 t^{-1} FFB	-75
Reduces specific weight	2.11 kg m^{-1}	< 1.5 kg m^{-1}	-29
Reduce vibration	10 m s^{-2}	< 2.5 m s^{-2}	-75

works out to about 25 million revolutions per month. This high speed movement causes severe wear and tear on the moving parts especially on the components which rub against each other. Rough handling by the operators is another factor that can cause machine breakdown.

In the new design, several elements had been considered as follows:

- the use of 'double bearing system' on both sides of the main-gear. This would improve stability of the gear (*Figure 2*). A single bearing system as in the old design only provides one-sided support to the main gear which causes the gear running off during the rough harvesting operation;
- to have an in-line cutting force that generates low vibration compared to the old design (*Figure 3*). Offset cutting line as in the old design will generate higher vibration compared to in-line cutting action as proposed in the new design;
- to shorten the distance of stroke from 10 mm to 6 mm (*Figure 4*). This can lower the magnitude of vibration of the machine during operation; and
- changing of material from cast-iron into high quality metal to improve strength on certain components especially the connecting-rod.

Shaft guider. Shaft guiders are placed inside the main pole to hold and guide the shaft to rotate smoothly to transfer rotational power to the cutting head efficiently. The unbalance shaft rotation will generate high vibration that would be transferred to the pole. The previous version of *Cantas* employs a single-sided bearing on the shaft guider that generates high vibration during rotating.

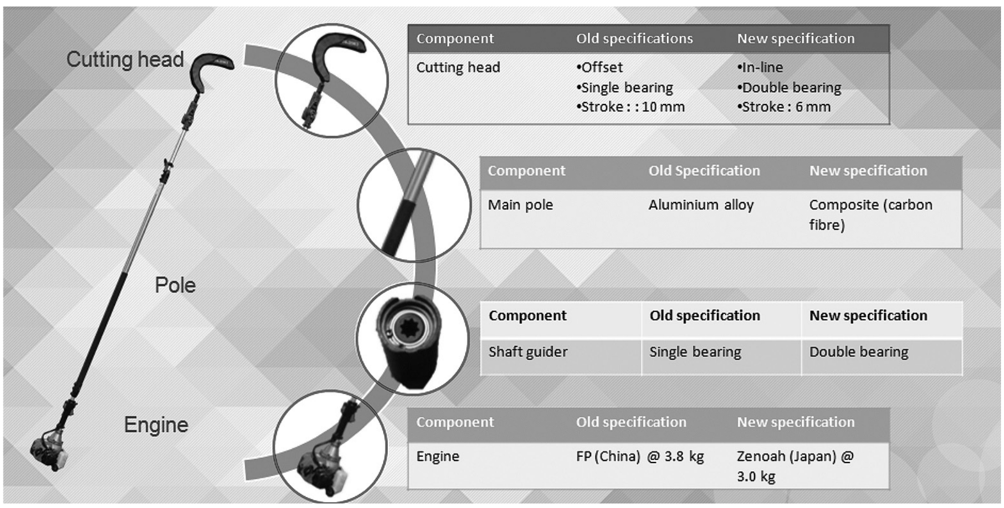

Figure 1. Proposed specification of the new design motorised cutter.

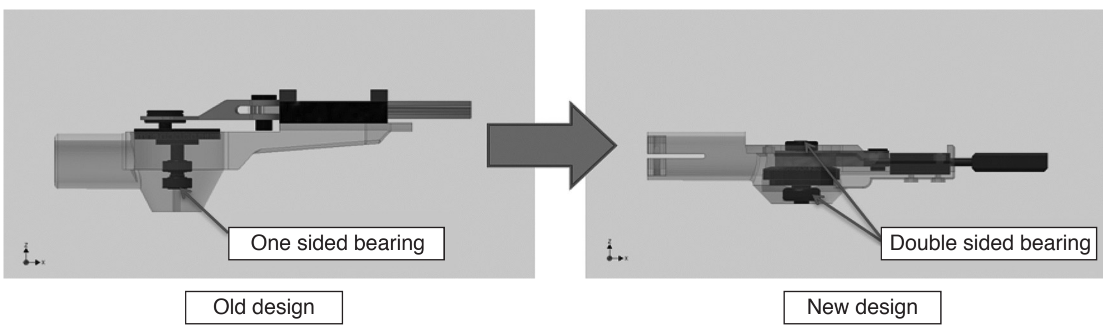

Figure 2. Previous version's design with one sided bearing (left) and new design with double-sided bearing (right).

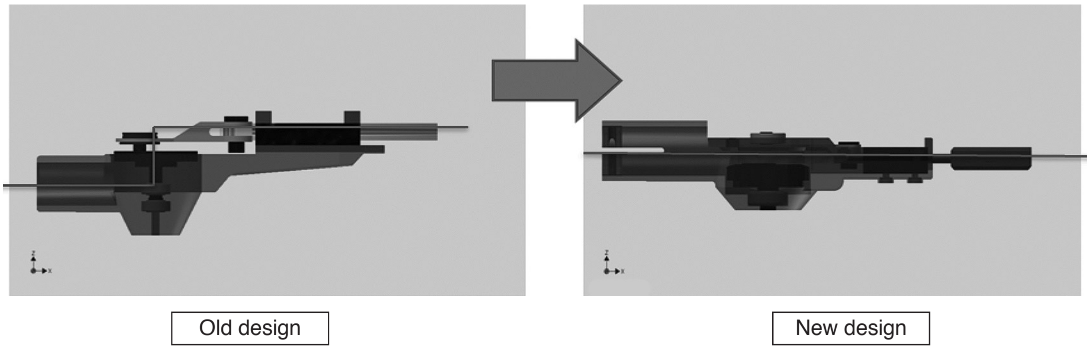

Figure 3. Previous version design with offset cutting action (left) and new design with straight cutting action (right).

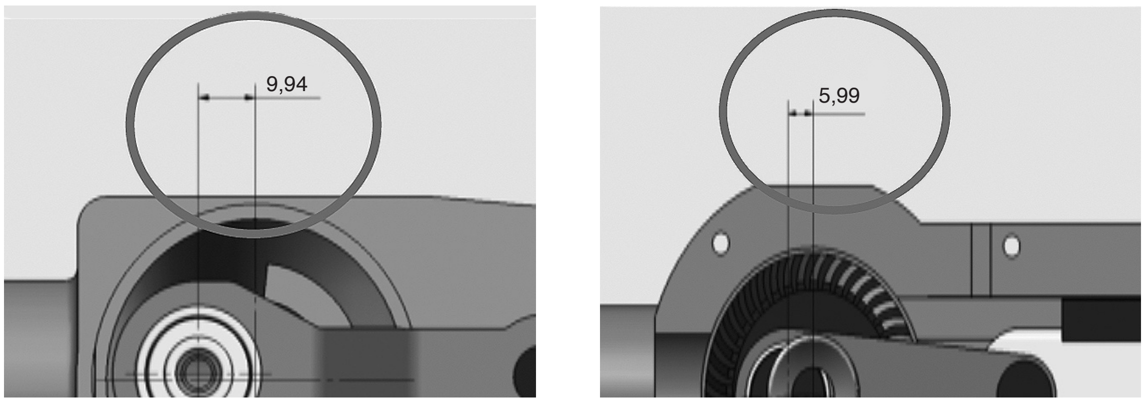

Figure 4. Displacements of old design (left) and new design (right).

In the new design, two-sided bearings are installed on the shaft guider that provides a better and steadier stability of the shaft that reduces vibration during rotating *(Figure 5*).

Weight Reduction

Pole design. The pole has been designed to have an oval shape as to increase surface contact area that provides a firm hand gripping during handling. The cross-section dimension is shown in *Figure 6*. The oval shape will increase the stiffness on the Y-axis where it is very crucial in the lifting operation to ensure the pole does not bend excessively. The ratio of Y- to X-axis is 1.14.

In the new design, the shape remains but the material is changed into composite material (carbon fibre) which is about 20% lighter compared to aluminum alloy grade 6061 as used in the previous version.

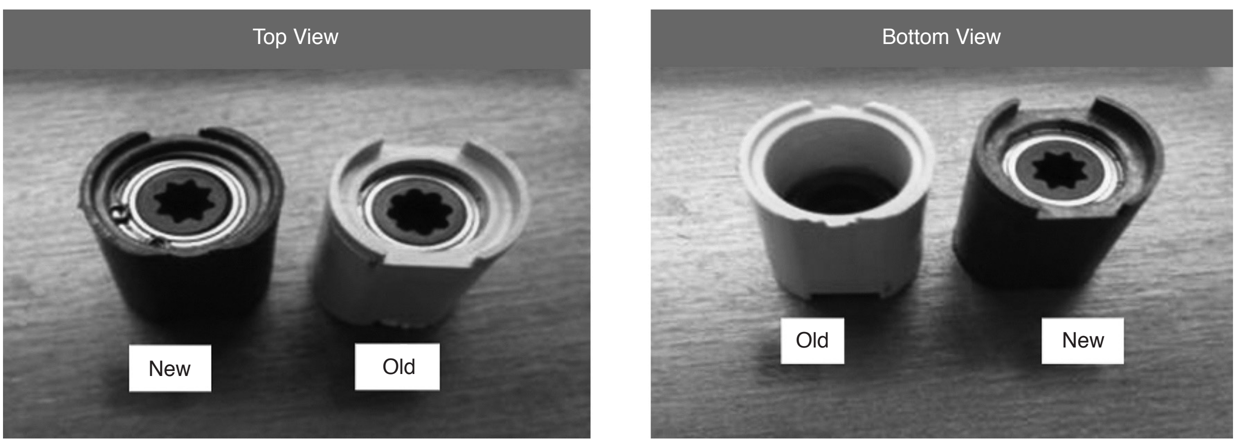

Figure 5. Old and new design of shaft guider.

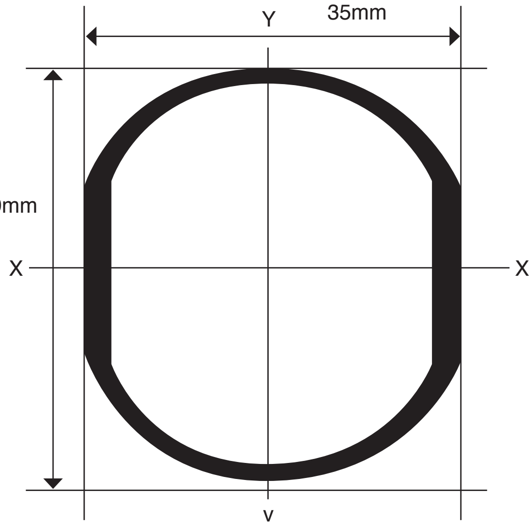

Figure 6. Cross-sectional dimension of the pole.

Engine. The previous version of *Cantas* was powered by a two-stroke petrol engine with the horsepower of between 1.3 to 1.5 hp. Various models of engines used were mostly imported from Germany, Japan, USA, China and Sweden. The weight of the engine ranged from 3.0 to 3.8 kg. In the new design, however, a smaller sized engine (1.1 hp) with a maximum rpm of 11 000 is used with the weight of 3.0 kg. With this engine, the weight is reduced by 21%.

Weight and reach. The weight of *Cantas* is proportionate to its length. The weight gets heavier when the length is increased. There are two main constraints that play a very significant role in harvesting pole design viz. the specific weight and stiffness (Abdul Razak *et al*., 1998a). A material with higher Young's modulus can be approximated as rigid. A stiff material needs more force to deform compared to a soft material. Stiffness is the rigidity of an object — the extent to which it resists deformation in response to an applied force [Equation (1) and *Figure 1*].

Stiffness (k) = force applied (F) / deformation (ϒ) .... [1]

For *Cantas* to be effective, the specific weight should remain low, but the stiffness should be set higher. High stiffness will reduce pole's deflection, where the combination of high stiffness and low weight can craft the pole to be made longer for higher harvesting reach. Several approaches have been identified to reduce weight *i.e.* (i) using a lighter but stronger material such as air-craft aluminium grade alloy, composite as well as polymer material, *etc.* (ii) reverse and re-engineering of several components such as the cutting head, pole and transmission system, and (iii) having a lighter engine but with equivalent power.

Prototype of *Cantas Evo*

The new prototype of the new generation *Cantas* is shown in *Figure 8*. This new version is called *Cantas Evo*.

Testing

Quality tests. Quality test was conducted to ensure the prototype meets the quality standard. The machine has to go through and must pass the following quality tests prior to field test, final specifications, and mass production for commercialisation.

a. Physical test. Physical test includes the machine's total length, weight and its specific weight.

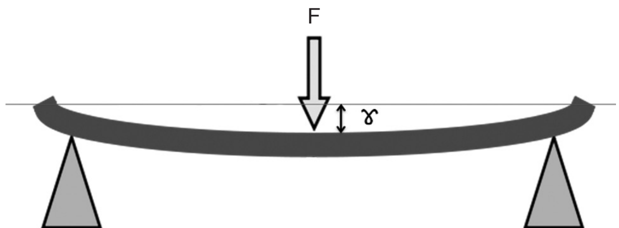

Figure 7. Calculation of stiffness.

Figure 8. Prototype of the new generation Cantas (Cantas Evo).

b. Functional test. Functional test is a test to verify whether the machine can do the job as it was designed for. The machine was tested to cut at least 10 oil palm fronds with the cutting time recorded. It must be able to cut a frond smoothly without much problem.
c. Drop test. In the drop test, the machine was dropped from different heights and angles (free fall) to see whether the machine/sample can stand the impact of falling. Two heights were set viz. 1 and 2 m with three different dropping angles viz. 30°, 45 and 60°.
d. Vibration test. Vibration test was carried out to measure the magnitude of vibration transferred to the hand of the user. Vibration level was measured at two points *i.e.* at the engine's throttle point (Point 1) and at the hand gripping point (Point 2), the point where the harvester holds the pole during harvesting (*Figure 9*). In the experiment, the magnitude of vibration was measured during cutting of frond. Dewesoft vibration equipment was used in this exercise.

   The parameter that was investigated in the experiment was hand-arm vibration (HAV). HAV is the vibration transmitted into workers' hands and arms. This can come from use of hand-held power tools, hand guided equipment or by holding materials being worked by hand-fed machines.

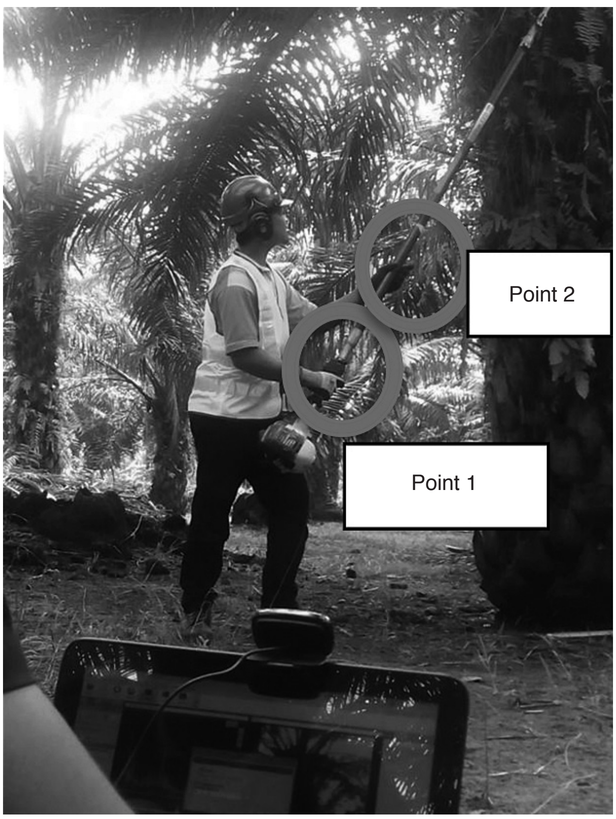

Figure 9. Vibration test during cutting operation.

   The Vibration Regulations include an exposure action value (EAV) and an exposure limit value (ELV) based on a combination of the vibration at the grip point(s) on the equipment or work-piece and the time spent gripping it. The exposure action and limit values were:

- a daily EAV of 2.5 m s^{-2} A(8) that represents a clear risk requiring management; and
- a daily ELV of 5 m s^{-2} A(8) that represents a high risk above which employees should not be exposed.

   EAV is a daily amount of vibration exposure above which employers are required to take action to control exposure. The greater the exposure level, the greater the risk and the more action employers will need to take to reduce the risk. For HAV the EAV is a daily exposure of 2.5 m s^{-2} A(8).

   ELV is the maximum amount of vibration an employee may be exposed to on any single day. For HAV, the ELV is a daily exposure of 5 m s^{-2} A(8). It represents a high risk above which employees should not be exposed.

   All the vibration tests followed the Control of Vibration at Work. Regulations 2005 (the Vibration Regulations) ISO 5349 (mechanical vibration – measurement and evaluation of human exposure to hand-transmitted vibration). The same procedures was used by Salihatun *et al*. (2014) in conducting a study on the effect of carbon fibre pole on HAV of palm fruit motorised cutter.

e. Engine performance test. Engine performance test was conducted to establish the performance curve *i.e.* torque and horsepower as well as other important data such as engine temperature and fuel consumption. The test was conducted using an Eddy Current Small Engine Dyno Test. In the experiment, the engine's speed variation was set from 2000 to 10 000 rpm. The engine performance test was made according to ISO 1585 (for rotary piston engines and reciprocating internal combuition engines).
f. Fatigue test. Fatigue test or repetitive test is a test to examine the durability of parts or components after being exposed to repetitive movements which is similar to actual operation in the field. A controller is used to activate the machine to run within a pre-determined period. The prototype will have to work on a design load of 20 kg. A minimum of 100 hr test is required to investigate wear and tear incidents of parts.

FIELD TEST

The field trial is a long-term evaluation conducted in commercial plantation to assess the machine's performance and repair cost. The trial was carried out in Boustead Kuala Muda Estate in Baling, Kedah, Malaysia the same place where the benchmark data on previous version of *Cantas* was taken. As the palms have increased in height, previous version of *Cantas* with its maximum reach of 5 m was not reachable anymore. *Cantas Evo* that could reach 7 m height was thus used to continue the mechanised harvesting operation in this particular plot.

The trial was commenced in September 2014. Two samples of *Cantas Evo* were used in the trial, namely Sample 1 and Sample 2. The samples were tested in a 271 ha plot of 13-year old palms with the harvesting heights in the range of 7 to 8 m.

Harvesting Operation

In the harvesting operation, two harvesting teams were formed, each team comprised of three workers *i.e.* one cutter using *Cantas Evo*, one helper (stacking fronds, cutting long stalks and arranging the cut FFB onto harvesting path) and one loose fruit collector. The payment was a sharing system where the income was equally divided among the team members. The harvested FFB were loaded and transported by a mechanical loader (mini-tractor with *Grabber*) to the roadside or collection points.

RESULTS AND DISCUSSION

Quality Tests

Physical test. *Table 5* shows the comparison of physical properties of the new generation *Cantas* (*Cantas Evo*) and the previous version of *Cantas*, while *Table 6* shows the physical properties of *Cantas Evo*.

The physical test conducted shows that the specific weight of *Cantas Evo* is 1.45 kg m^{-1} compared to 2.11 kg m^{-1} for previous version of *Cantas*, proving that *Cantas Evo* is lighter by 31.3%.

Functional test. The results of functional test are shown in *Table 7*. A total of 23 fronds and 10 FFB were cut from 10 palms. It was witnessed that the machine was easy to handle, easy to perform cutting operation and the sickle was sharp.

Drop test. *Table 8* shows the result of drop test from two different heights and four dropping angles. Experiment carried out proved that the machine was tough with no break, dent or malfunction on any parts of the machine.

Vibration test. The magnitude of HAV of *Cantas Evo* and previous version of *Cantas* are shown in *Table 9*. For *Cantas Evo*, the vibration level at Points 1 and 2 were 0.6 and 0.4 m s^{-2}, respectively, while for previous version of *Cantas*, the vibration levels at Point 1 and 2 were 9.8 and 10.2 m s^{-2}, respectively. Therefore, the vibration level of previous version of *Cantas* were above the EAV value *i.e.* 2.5 m s^{-2} [ISO 5349 (Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration)]. The test has proven that *Cantas Evo* is safe to be used in a period of 8-hr working a day.

Engine performance test. The engine used was a Japanese made engine (Zenoah brand). The performance curve of the engine is shown in *Figure 10*. Test conducted showed that the maximum horsepower achieved was 1.1 hp at 8300 rpm, while the maximum torque was 1.3 N-m at 5700 rpm.

TABLE 5. PHYSICAL PROPERTIES COMPARISONS OF NEW GENERATION *Cantas* (*Cantas Evo*) *vs.* PREVIOUS VERSION OF *Cantas*

Tool	Length (m)	Weight		Engine model	Main pole material
		Total (kg)	Specific weight (kg m^{-1})	(bp)	
Cantas Evo	6.21	9.00	1.45	Zenoah 1.1	Composite (carbon fibre)
Previous version *Cantas*	4.02	8.50	2.11	Stihl 1.5	Aluminium alloy

TABLE 6. SPECIFICATION OF *Cantas Evo*

Description	Results	Remark	Comments
Maximum length (m)	6.21	-	-
Minimum length (m)	5.00	-	-
Centre of gravity (m) from engine	1.40	Short/moderate/far	Moderate
Deflection at *cofg* (cm)	7.00	Low/moderate / high	Low
Total weight (kg)	9.00	Light/moderate/heavy	Moderate
Specific weight (kg m^{-1})	1.45		
Fuel consumption (litre hr^{-1})	0.32 litre-hr^{-1}	Low consumption/ moderate consumption/ high consumption	Moderate

TABLE 7. FUNCTIONAL TEST OF *Cantas Evo*

Palm No.	Total fronds	Total FFB
1	2	1
2	3	1
3	2	1
4	3	-
5	2	2
6	2	-
7	1	1
8	2	1
9	4	2
10	2	1
Total	23	10
Remark	Good in handling, easy to cut and sharp	

Note: FFB - fresh fruit bunches.

TABLE 8. RESULTS OF DROP TEST OF NEW GENERATION *Cantas*

	Height	Dropping angle	Observation
1		90°	R1 Good condition R2 Good condition R3 Good condition
2		60°	R1 Good condition R2 Good condition R3 Good condition
3	1.00 m	45°	R1 Good condition R2 Good condition R3 Good condition
4		30°	R1 Good condition R2 Good condition R3 Good condition
5		90°	R1 Good condition R2 Good condition R3 Good condition
6		60°	R1 Good condition R2 Good condition R3 Good condition
7	2.00 m	45°	R1 Good condition R2 Good condition R3 Good condition
8		30°	R1 Good condition R2 Good condition R3 Good condition

Note: R - replicate.

The results of performance test were as follows:

$$Hp = -0.000\ rpm^2 + 0.04\ rpm + 0.001 \quad [2]$$
$$R^2 = 0.938$$
$$Torque = 0.000\ rpm^2 + 0.05\ rpm + 0.432 \quad [3]$$
$$R^2 = 0.689$$

Fatigue test. Test conducted showed that there was no breakdown incident within 100 hr of fatigue test.

TABLE 9. COMPARISON OF VIBRATION LEVEL OF *Cantas Evo* AND PREVIOUS VERSION OF *Cantas*

	Vibration level (m s^{-2})		Remark
	Point 1	Point 2	
Cantas Evo	0.6	0.4	Low - safe to use
Previous version *Cantas*	9.8	10.2	High

The engine temperature ranged from 80°C to 114°C which is a normal temperature as recommended, fuel consumption at 0.32 litre hr^{-1} with the total cycle of 5066 cycle run in 21 days or about 50 cycle hr^{-1}.

Table 10 shows the summary of results of the quality tests of *Cantas Evo*.

FIELD EVALUATION

Table 11 shows the comparison of results of *Cantas Evo* against previous version of *Cantas* in Boustead Kuala Muda Estate in Baling, Kedah, Malaysia. The data were taken from September 2014 to December 2015. This data was compared against data of previous version of *Cantas* which was taken in previous year *i.e.* from January to December 2013. Side by side comparison trial cannot be made as the palms were already reaching 7 to 8 m harvesting height which was not reachable by the previous version of *Cantas*. Trials conducted revealed that there is no significant difference in terms of harvesting productivity of *Cantas Evo* (5.38 t FFB per day) against previous version of *Cantas* (5.31 t FFB per day).

However there was a significant reduction on the repair cost where C*antas Evo* recorded only RM 0.39 t^{-1} FFB compared to previous version of *Cantas* at RM 4.03 t^{-1} FFB, almost 90% cost reduction. From this reduction, the estate will be able to save about RM 3000 per cantas per year. This low repair cost was made possible because *Cantas Evo* had fewer breakdowns *i.e.* only RM 594 per machine for period of September 2014 to December 2015 or RM 37 per machine per month. While for previous version of *Cantas*, the repair cost was RM 3407 per machine for the period January to December 2013 or RM 284 per machine per month.

Figure 11 shows the productivity of *Cantas Evo* for the period of October 2014 to December 2015. During peak crop *i.e.* from April to June 2014, the machine's productivity can reach as high as 200 t per month or about 8 t per day.

Table 12 shows the overall comparison of data before and after improvement was made. It can be seen that the repair cost, specific weight and vibration were reduced by 90%, 31% and 95%, respectively. Thus, the project has met its main objectives that is to improve durability, and to reduce weight and vibration.

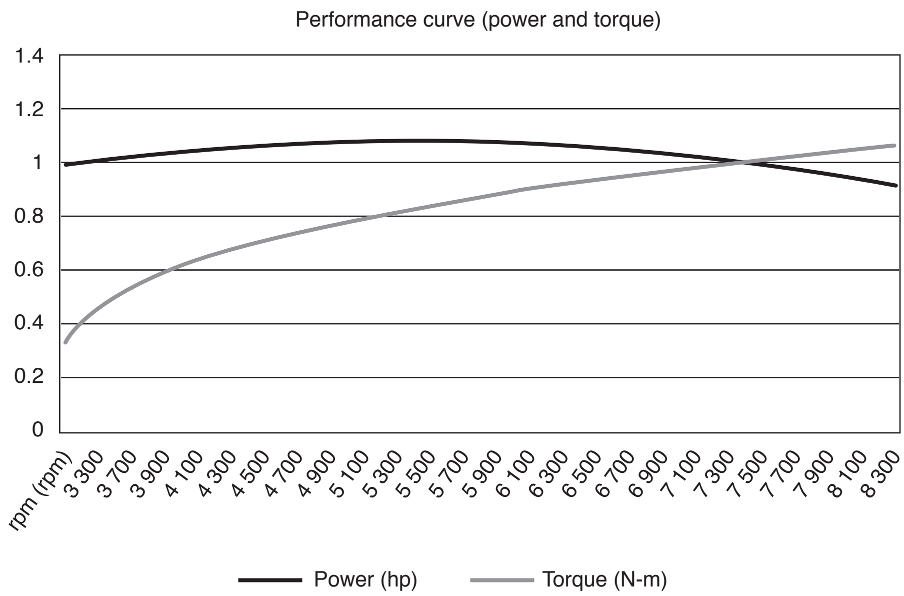

Figure 10. Performance curve of Zenoah engine (power and torque).

TABLE 10. SUMMARY OF RESULTS OF THE QUALITY TESTS OF *Cantas Evo*

Type of test	Result	Remarks
Functional test	Pass	Able to cut 10 fronds without problem.
Drop test	Pass	The sample was not damaged or dented after being dropped from 2 m height.
Vibration test	At throttle: At hand gripping point:	Below the EAV limit of 2.5 m s^{-2}. Engine performance test.
Engine performance test	Max rpm: 10 000 Max hp: 1.1 Max torque : 1.3 N-m	- - -
Engine endurance test	Pass Average temperature: 110°C average fuel consumption: 0.16 litre hr^{-1}	The engine was dismantled after 100 hr test to see the wear and effect on the piston, piston rings. No severe damage and wear and tear.
Fatigue test	Pass	The sample was dismantled and no severe wear and tear observed.

Note: EAV - exposure action value.

ECONOMIC ANALYSIS

Cost-effectiveness

Cost-effectiveness is measured in terms of the total FFB harvested for the period of its economic life against the price of the machine (Stanner, 1992a,b) as in the following equation:

$$\text{Cost-effectiveness, Ec} = \frac{\text{Machine price (RM)}}{\text{Total FFB harvested}} \quad \ldots\ldots\ [4]$$

$$\text{Therefore the cost-effectiveness of } \textit{Cantas Evo} = \frac{\text{RM 3800}}{\text{5.38 t per day x 300 days x 2 years}}$$

$$= \text{RM 1.18 t}^{-1} \text{ FFB}$$

The following assumptions were made:

Machine price, M	:	RM 3800
Economic life, E	:	2 years
Productivity, P	:	5.38 t per day
Labour cost, L_c	:	RM 50 per day
Working days per year	:	300 days

Payback Period

Table 13 shows a simple cash-flow analysis with the following assumption:

Repair and maintenance cost	:	RM 0.39 t^{-1} FFB
Fuel cost	:	RM 0.32 t^{-1} FFB
Harvesting cost	:	RM 21.24 t^{-1} FFB

TABLE 11. COMPARISON OF *Cantas Evo vs.* PREVIOUS VERSION OF *Cantas*, BOUSTEAD KUALA MUDA ESTATE, BALING, KEDAH, MALAYSIA

	Cantas Evo	Previous version of *Cantas*
No. of units used	2	10
Test period	Sept 2014 - Dec 2015	Jan - Dec 2013
Total day	557	1 588
Total hour	1 864	6 040
Productivity (t FFB)	2 998	8 436
Productivity per day (per day)	5.38	5.31
Total fuel cost (RM)	972	2 791
Total repair cost (RM)	1 188.15	34 071
Total labour cost (RM)	6 1769	173 813
Total running cost (RM)	6 3706	211 303
Running cost per tonne FFB (RM t^{-1})	21.24	25.04
Repair cost per tonne FFB (RM t^{-1})	0.39	4.03

Note: FFB – fresh fruit bunches.

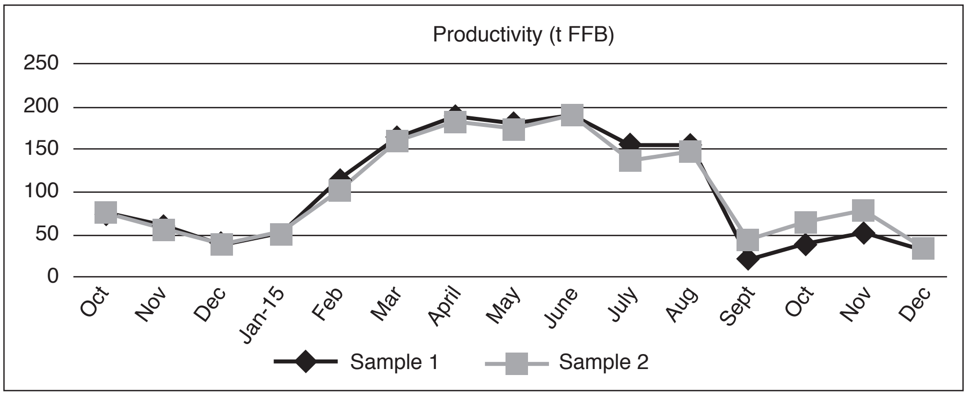

Figure 11. Monthly productivity of Cantas Evo *from October 2014 to December 2015 at Boustead Kuala Muda Estate, Kedah, Malaysia.*

TABLE 12. ACHIEVEMENT OF GAP ANALYSIS

		Before		After	
Objective	Current standing	Target	% Gap	Actual	% Achieved
Improve durability	Repair cost at RM 4.03 t^{-1} FFB	< RM 1.00 t^{-1} FFB	-75	0.39	-90
Reduces specific weight	2.11 kg m^{-1}	< 1.5 kg m^{-1}	-29	1.45	-31
Reduce vibration	10 m s^{-2}	< 2.5 m s^{-2}	-75	0.5	-95

Note: GAP -

TABLE 13. SIMPLE CASH-FLOW ANALYSIS FOR THE OWNER OF *Cantas Evo* (per machine)

Month		1	2	3	4	5	6	7	8	9	10	11	12
Inflow:													
FFB sales	8 888		2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963
	8 888	0	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963	2 963
Inflow:													
CAPEX		3000.00											
OPEX			177.75	195.53	215.08	236.59	260.24	286.27	314.89	346.38	381.02	419.13	461.04
Total outflow	588.35		177.75	195.53	215.08	236.59	260.24	286.27	314.89	346.38	381.02	419.13	461.04
Profit (deficit)	5 299	(3000.00)	2 784.75	2 766.98	2 747.42	2 725.91	2 702.26	2 676.23	2 647.61	2 616.12	2 581.48	2 543.37	2 501.48
Cumulatitive			(215.25	2 551.73	5 299.15	5 473.34	5 428.17	5 378.49	5 323.84	5 263.72	5 197.59	5 124.85	5 044.84
IRR		75%											
NPV		RM 3 529.57											
Payback period		3.52	month										

Note: CAPEX - Capital expenditure.
OPEX - Operational expenditure.
FFB - fresh fruit bunches.
IRR - internal rate by return.
NPV – net present value.

Contingency cost	:	10%
Income per month	:	RM 2962
Operational cost per month	:	RM 177.50

The table shows that the internal rate of return (IRR), net present value (NPV) and the payback period of *Cantas Evo* were 75%, RM 3529 and 3.52 months, respectively. It means that if the average daily harvesting productivity of 5.38 t, 25 working days/month, the payback period will come to about 3.52 months.

Cost per tonne FFB

For the economic analysis, the fixed cost is the machine (*Cantas Evo*), while variable costs are labour, fuel and lubrication, and repair and maintenance. The operational cost per tonne FFB was calculated using a straight-line depreciation method. The details of the calculation are shown in *Table 14* where the operational cost came to RM 11.10 t^{-1} FFB, which is very attractive and cost-effective enough for the harvesters or estates to use *Cantas Evo*.

CONCLUSION

This project has met its objectives where a new generation *Cantas*, called *Cantas Evo*, was successfully designed, developed and tested. *Cantas Evo* with its new design of cutting head, pole, shaft guider, pole gripper and engine was found to be superior compared to the previous versions in terms of quality, weight and vibration. *Cantas Evo* passed all the required quality tests *i.e.* physical, functional, drop, vibration, fatigue and engine's performance tests. The specific weight of *Cantas Evo* was 1.45 kg m^{-1} compared to 2.11 kg m^{-1} for previous version of *Cantas*, proving that *Cantas Evo* is 31.3% lighter than the previous version of *Cantas*. While the vibration of *Cantas Evo* was very much below the limit which proved that it is safe to be used for 8 hr working a day.

Long-term field trial conducted in Boustead Kuala Muda Estate in a plot of palms with 7 m harvesting height showed that the harvesting productivity was 5.38 t FFB day^{-1} with the repair cost of RM 0.39 t^{-1} FFB. When compared to previous version of *Cantas*, the repair cost of *Cantas Evo* is very much lower which in-turn could help the estate to save operational cost significantly. However, there was no significant different on harvesting productivity *i.e.* 5.38 t FFB per day for *Cantas Evo* and 5.31 t FFB per day for previous version of *Cantas*.

Besides the features of high quality, lighter, low vibration and lower repair cost, the extra benefit of *Cantas Evo* is that it is suitable to harvest up to 7 m harvesting height as proven in Boustead Kuala Muda Estate.

It is accepted by operators due to its high efficiency, ergonomically designed, which offer comfort during handling, easy to operate and safe to use. Thus, as an extra benefit, it is therefore recommended that it is not only used for harvesting FFB, but can also be expanded for use as a pruning tool. With a good maintenance and care, it is envisaged that the machine would be more cost-effective in the long run.

It is noted that the combination of hardware and software is very crucial to a success of any new invention. In this case, the hardware is the machine itself and software is the attitude of the operator and the system used as well as commitment from the management. A good combination of these two will be the main factor of successful mechanisation.

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TABLE 14. COST ANALYSIS OF *Cantas Evo* USING STRAIGHT LINE DEPRECIATION

Description	Calculation	Cost (RM per day)
Productivity	5.38 t day^{-1}	-
Depreciation [price/(life span x 300 days yr^{-1})]	3800/(2 yr x 300 days)	6.33
Fuel (petrol) @ 1 litre per day	1 x RM 2 $litre^{-1}$	2.00
R&M cost @ 10% per year of purchase price	10% x 3800/(300 days yr^{-1})	1.27
Lubrication cost @ 10% of R&M	10% x 1.27	0.13
Labour cost	-	50.00
Total		59.73
Cost per tonne FFB = total cost/productivity per year	RM 59.73 per day/5.38 t day^{-1}	11.10

Note: R&M – repair and maintenance.

REFERENCES

ABDUL HALIM HASSAN; ABD RAHIM, S and AHMAD, H (1988). An improved FFB harvesting pole – with special reference to PORIM'S aluminium pole. Paper presented at the National Oil Palm/ Palm Oil Conference - Current Developments, 11-15 October 1988, Kuala Lumpur.

ABDUL RAZAK JELANI; ABD RAHIM, S and AHMAD, H (1998a). The effects of physical characteristics of aluminum pole on the harvesting productivity of tall palms. *PORIM Bulletin No. 36*: 13-20.

ABDUL RAZAK JELANI; DESA, A; AHMAD, H; AZMI, Y and JOHARI, J (1998b). Force and energy requirements for cutting oil palm frond. *J. Oil Palm Res. Vol. 10(2)*: 10-24.

ABDUL RAZAK JELANI and AHMAD HITAM (2002). Design and evaluation of an improved aluminium harvesting pole (*Hi-Reach*) for tall palm harvesting. *Oil Palm Bulletin No. 44.*

ABDUL RAZAK JELANI; AHMAD, H; JOHARI, J; MALIK, N; YOSRI, G and OMAR, A (2008). Cantas™: A tool for the efficient for harvesting oil palm fruit bunches. *J. Oil Palm Res. Vol. 20(2)*: 548-558.

ABDUL RAZAK JELANI; RIZAL, A; IKMAL, H; SALIHATUN, M S and ABD RAHIM, S (2013). Oil palm motorised cutter (*Cantas*): A tool for improving workers productivity. *Proc. of the PIPOC 2013 International Palm Oil Congress - Agriculture Conference*. MPOB, Bangi.

AZMAN ISMAIL; SITI MASHANI, A and ZURAIHAN, S (2015). Labour productivity in the Malaysian oil palm plantation sector. *Oil Palm Industry Economic J. Vol. 15 (2)*: 1-10.

ECONOMIC TRANSFORMATION PROGRAMME (ETP) (2012). *Annual Report 2012*.

HEALTH and SAFETY EXECUTIVE (2013). *Hand Vibration at Work*. *User Guide.*INDG175 (rev3) Published by the Health and Safety Executive.

KUALA MUDA HARVESTING REPORT (2013). Unpublished data. Boustead Plantations Berhad, Ladang Kuala Muda Estate, Kedah, Malaysia.

MOHD RAMDHAN KHALID and ABD RAHIM SHUIB (2014). Field evaluation of harvesting machines for tall palms. *J. Oil Palm Res. Vol. 26 (2)*: 125-132.

MPOB (2016). Economic and Industry Development Division.

SALIHATUN, M S; ABD KADIR, M S; RAMLEE, M P; RAHIM, E A; ABDUL RAZAK, J; AHMAD, M R and KASRON, Z (2014). The effect carbon fiber pole on hand-arm vibration of palm fruit motorised cutter. *Applied Mechanics and Materials Vol. 660*: 521-525.

STANNER, G H (1992a). Investigating the true cost of conventional harvesting tools. Paper presented at the Eastern Plantation Agency Bhd Seminar, Johor, June 1992.

STANNER, G H (1992b). Field trials of an improved oil palm harvesting tool. *The Planters Vol. 68*: 485-497.