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Evaluation and Comparison of the Ergonomics, Performance and Economics of Battery-Powered and Engine-Powered Palm Oil Harvesting Tools:Cantas Elektro

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ABSTRACT

The Malaysian Palm Oil Board (MPOB) has introduced an engine-powered palm oil harvesting tool called CANTAS that can double the conventional harvesting output. However, there are several issues that are affecting the endurance and comfort of the harvesters. This paper discusses the comparison in the context of ergonomics, performance, and ecconomics of a battery-powered CANTAS called CANTAS Elektro, which could overcome the issues of the engine-powered CANTAS. The prototype was tested in the laboratory and the field to investigate its ergonomic factors. Test results revealed that CANTAS Elektro was more ergonomic than CANTAS as the deflection, configuration, temperature, noise, and vibration levels of the former were 38%, 42%, 59.8%, 12.7%, and 45.8–65.2% less than those of the latter, respectively. The harvesting productivity increased by 26.5% from 5.63 to 7.04 t/day, with an estimated saving of operational cost of RM1013/machine/yr. The take-home pay of workers was increased by 29% from RM81 to RM107/man-day, apart from other fringe benefits. It was proven that the battery-powered machine was more cost-effective than the engine-powered machine, in addition to other advantages such as being carbon emission-free, clean, easy to maintain, less complicated and easy to handle.

Keywords: Harvesting; palm-oil motorised cutter; harvesting tool; battery driven harvesting tool

INTRODUCTION

Palm oil is one of the sources of national income. As of December 2020, the total area planted with palm oil in Malaysia was about 5.87 million hectares, contributing to the gross income of approximately RM73.25 billion of the export revenue to the country (Parveez et al. 2021). It is well known that at present, the industry is highly dependent on foreign labour to carry out field operations. The latest statistics show that there are about 340,283 foreign workers in this industry, which accounts for nearly 77.8% of the total field workers in the plantation sector (Malaysian Palm Oil Board 2018). The harvesting operation, which is the core activity in the palm oil plantation, is dominated by foreign workers. The shortage of foreign workers due to the pandemic is a critical issue that needs to be seriously addressed. Several ways and means to deal with the issue have been identified and discussed. Among those is by mechanizing the harvesting operation, which can potentially reduce the need of foreign workers.

Effective harvesting requires at least two factors, namely effective harvesting tools and sufficient harvesters, to produce the optimum output within the recommended harvesting cycles of seven to 13 days (Castillo et al .2017). Manual harvesting that involves the use of sickles or chisels can only produce about 0.99 tonnes of fresh fruit bunches (FFB) per day (Azman et al. 2015). Estates owners are now looking for more efficient harvesting tools, which can increase individual daily harvesting productivity and ultimately reduce the number of workers. The harvesting productivity should be increased to approximately 4 t/ha/man-day if the country wishes to reduce the labour requirements significantly.

FIGURE 1. CANTAS (engine powered)

Palm oil motorised cutter (CANTAS) was introduced by MPOB to the industry in 2007 and an improved version (CANTAS Evo) with several advanced features was introduced in 2014. CANTAS Evo is suitable for harvesting FFB from palms up to seven metres in height. CANTAS increases harvesting productivity and improves the earnings of harvesters, which can reduce the number of workers on the payroll that are currently dominated by foreigners (Abdul Razak et al. 2018). CANTAS (see *Figure 1*) is a motorised cutter specifically designed for harvesting FFB and cutting fronds. It is powered by a small petrol engine and utilised either a specially designed C-shaped sickle or chisel as the cutting knife. The technology belongs to MPOB and the patents were filed in Malaysia, Indonesia, Thailand, Brazil, Costa Rica, and Columbia. CANTAS can accelerate the harvesting operation and thus, increase the harvesting productivityIn term of biomechanics, there are two leg positions referring to ankle joint movement; plantar flexion and dorsiflexion (Keene 2010). The plantar flexion is referred to the pressing of the pedal, while dorsiflexion is referred to the releasing of the pedal. Dorsiflexion happens when the driver releases the pedal with the ankle joint angle is less than 90° and at the maximum of 70°. Meanwhile, the plantar flexion occurs when the driver presses the pedal with the ankle joint angle greater than 90° and at the maximum of 140°.

PROBLEM STATEMENTS

Since the introduction of CANTAS to the market, MPOB received various feedback from users. It was reported that CANTAS could double the harvesting productivity and reduce the number of workers by 50% (Abdul Razak *et al.* 2008). However, there were also comments on the ergonomic issues related to the engine, such as the production of smoke, heat, noise, vibration, as well as the heavy weight of the machine. All of these will affect the comfort and endurance of the harvesters, which consequently will affect their daily harvesting productivity (Abdul Razak *et al.* 2018). Petrol engines also require extra attention, especially before the work commencement in the morning. This includes the need to mix petrol and lubrication oil, check and clean the spark plug, inspect the starting cable, and many more. All these works could demotivate the operators as they have lost considerable amount of time maintaining the machine instead of harvesting the FFB. Issues surrounding the rising price of fuel and spare parts also warrant other effective alternatives.

This study is also in line with the initiative of the government to adopt green technology, which is more environmentally friendly and better for the people and the planet. All these concerns have prompted action for improvement to make the machine more ergonomic and easier to handle and maintain. After considering all the issues associated with the engine-powered CANTAS, a proposal was made to replace the engine with a battery-powered electric motor.

The main objective of this study was to compare and discussed in the context of ergonomics, performance, and economics of a between battery-powered and engine-powered CANTAS. Amongst other the expected benefits of the technology are that it is a green technology where instead of utilising petrol engine (as in the current CANTAS), this new technology employs electrical motor as the main power source. Thus, it requires no fuel, lubrication oil (2T), and spark plugs. In addition, it is free of emissions. The use of electrical motor has made the technology is more silent, lighter and, generates low vibration. It is a user-friendly machine which eliminates all the clumpsy works such as refuelling, mixing petrol with 2T oil, inspecting spark plug and whatnots as in petrol engine. One of the important elements that has been considered in the use of electrical motors is cost, where this new technology is expected to have fewer breakdowns that lead to a lower repair and maintenance cost as it has less mechanical parts compared to CANTAS.

MATERIALS AND METHODS

THE PROTOTYPE

In this work, the designed and developed battery-powered harvesting tool was called CANTAS Elektro. Its pole and cutting head were the same as those of the previous CANTAS. The only difference was the motor set, which comprised an electric motor and a battery. The specifications of the motor and battery are listed in *Table 1*. *Figure 2* shows the schematic diagram of CANTAS Elektro, while *Figure 3* shows the final prototype.

The tool was equipped with two 18V 6.0 Ah Lithium-ion batteries to power up the electric motor and the whole system. The motor was a brushless type, which has several advantages over a brushed motor, such as fewer overall maintenance, higher efficiency, smaller size, and the ability to operate at a higher speed. A C-sickle was used as the cutting knife, which is suitable for a harvesting height of 2.5–3 meters.

Table 2 shows the technical specifications differences between CANTAS Elektro and CANTAS.

TABLE 1. Motor and battery specifications

Item	Specifications	
Motor	Producer: Japan (Brushless Motor)	
	Rated power	600W
	Rated voltage	36V
	Rated current	6.0Ah
	Rated speed	9700 RPM
Battery	Battery (Lithium-Ion Direct Current)	
	Rated voltage	18 V
	Rated power consumption of battery	18V x 6.0Ah x 2 batteries = 0.216kWh
	Charging time	1 hr/day
	(2 units battery is required; thus, the total voltage is 36V)	

FIGURE 2. Schematic diagram of CANTAS Elektro (CAD Inventor Software)

FIGURE 3. The prototype of CANTAS Elektro

TABLE 2. Specifications differences between Cantas Elektro Vs Cantas

Descrption	CANTAS ELEKTRO (Battery powered)	CANTAS (Engine powered)
Activator	DC Electrical motor	Petrol engine
Power source	DC Battery	Fuel (petrol)
Transmission	Electrical and mechanical (shaft and bearings)	Mechanical – shaft and bearings
Cutting knife	C-sickle	C-sickle

SCOPE OF STUDY

Four tests were conducted, namely physical, laboratory, functional, and field tests. The details of the tests are elaborated on in the following sections.

PHYSICAL TESTS

In the physical tests, the overall length (L), weight (W), point of the centre of gravity (cofg), and deflection (d) of the prototype were measured. The tests were conducted in a workshop and the equipment used included a measuring tape and a balance.

LABORATORY TEST

The laboratory tests comprised noise, voltage depletion, temperature, and vibration tests. The aim of the tests was to ensure the product meets certain standards and quality requirements. Table 3 lists down the type of tests, as well as their corresponding equipment and procedures. All tests were conducted in the Quality testing laboratory at the Farm Mechanization Unit of MPOB in Bangi Lama, Selangor.

TABLE 3. Tests, Equipment and Procedures

Test	Equipment	Procedures
Noise test	Noise meter	Measures the level of noise produced by the machine. It should not exceed 85 decibels. Standard: Occupational Safety and Health Act of 1970 (Public Law 91-596) (DHHS (NIOSH) Publication No. 98–126)
Voltage depletion test	1. Specially test jig 2. Voltmeter 3. Temperature gauge	Measures how long the power (voltage) in the battery can last before it is fully drain out. The test monitors the voltage of the battery as well as temperature of the electric motor. The machine will be placed on a specially test jig and simulated based on real condition. No load will be applied in the test.
Temperature test	Temperature gauge	Measures the electrical motor’s temperature
Vibration test	SIRIUS-i vibration equipment (serial number D00C018C2B) manufactured by Dewesoft.	Measures the magnitude of vibration developed by the machine that will be transmitted to the operator’s hand. The magnitude of vibration will be measured during cutting of frond. Standard : ISO 3985

FUNCTIONAL TEST

The functional test was conducted in the field to investigate and evaluate the functionality of the prototype. This was to ensure the prototype was able to cut fronds and FFB effectively. The test also aimed at determining the performance of the prototype in the harvesting and pruning activities. The time required to cut fronds and FFBs was recorded and evaluated. The total number of palms attended, as well as the number of fronds and FFB cuts were also counted and recorded. The voltage of the battery was recorded at the beginning and the end of the test.

BATTERY VOLTAGE DEPLETION TEST

The battery voltage depletion test aimed to determine how long the power (voltage) in the battery can last. It was conducted in the quality testing laboratory at MPOB according to the standard testing method (Abdul Razak *et al.* 2015). In addition, the motor temperature was measured and recorded simultaneously.

VIBRATION TEST

The vibration test was carried out to measure the vibration magnitude of the machine that was transferred to the hands of the harvester. The vibrations were measured at two points, namely at the throttle and on the pole, at which the harvester holds during harvesting (see *Figure 4*). The hand-arm vibration is the term used to describe the vibration that is transmitted to the hands and arms of workers, as stated in the Vibration Regulations (HSE 2012). In the test, the magnitude of vibration was measured during the cutting of fronds using the Dewesoft vibration equipment.

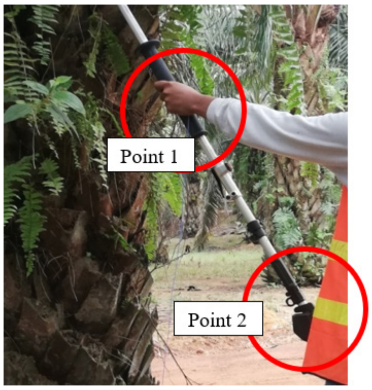


FIGURE 4. Vibration measurement at pole point (Point 1) and throttle point (Point 2)

FIELD TEST

The field test was conducted to investigate the actual performance of the prototype in the actual work environment. A commercial estate was chosen as the trial site and the machine was used by the estate workers. The trial site with a total area of approximately 136 ha was located in Batu Pahat, Johor. It was planted with DXP planting materials and the palms were seven to nine years of age at the time of the test. The harvesting height was around two to three meters with a bunch weight of 12–15 kg. The topography of the trial site was hilly and undulating.

HARVESTING SYSTEM

Two units of CANTAS Elektro were used in the trial. They were used by two harvesters, who had never used any type of motorised cutter before, specifically CANTAS. A one-week training period was given to ensure they were familiar with the machines. Each harvester was helped by a worker to carry out other tasks comprising stacking fronds, collecting loose fruits, and evacuating the FFB and loose fruits to the roadside or collecting platforms. In summary, two teams were formed for this trial, with a total of four workers involved. The period of the field trial was four months, starting from January to April 2021. Data on productivity, as well as operating and maintenance costs (repair, part replacements, etc.) were recorded and analysed. Simultaneously, two units of CANTAS and four workers were employed at the adjacent plot with the same palms and environment condition. At the end of the test, the performance of CANTAS and CANTAS Elektro was compared.

RESULTS AND DISCUSSIONS

PHYSICAL AND LABORATORY TEST

Table 4 shows the results of the laboratory tests for CANTAS Elektro and CANTAS. The length and weight of CANTAS Elektro were 2.5 m and 7.0 kg, respectively. In contrast, the length and weight of CANTAS were 3.6 m and 9 kg, respectively. It should be noted that the main factors that affect the comfort of the workers while handling the machine are the specific weight, deflection, and the point of the centre of gravity (cofg). It can be seen from the results that CANTAS Elektro had lower deflection, and cofg as compared to CANTAS.

The noise level of CANTAS Elektro was 60 dB, which was 12.7% lower than that of CANTAS, which was 79 dB. The former was much lower than 85 dB, which is the maximum noise limit recommended by the Occupational Safety and Health Act of 1970 ((Public Law 91-596) (DHHS) (NIOSH) Publication No. 98–126)) (Murphy & Franks 2002). In addition, the operating temperature of CANTAS Elektro was 41°C, which was 59.8% lower than the operating temperature of CANTAS of 102°C. The results prove that electric motors generate much lower noise and heat than petrol engines, which consequently give more comfort to the operators when handling the harvesting tool.

The results of the vibration test show that the vibration of CANTAS Elektro was much lower than that of CANTAS. The magnitude of vibration at P1 and P2 were significantly reduced by 45.8 and 65.2 %, respectively. The magnitude of vibration at the pole and throttle of CANTAS Elektro were 1.3 and 0.8 m/s^2, respectively, which were far lower than the threshold level of 2.5 m/s^2 (HSE 2012). This indicates that the tool is safe to be used for the whole eight-hour working period a day. A tool with lower vibration will be more comfortable to handle and thus, the operators can maintain their endurance over a longer period and this will improve their daily productivity and income.

TABLE 4. Results Of Physical And Laboratory Test

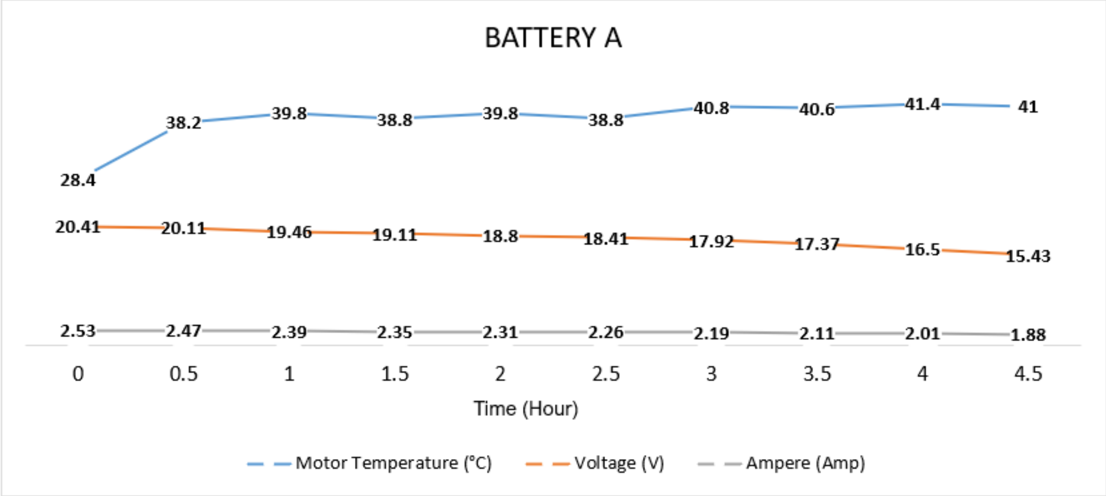
Description	CANTAS Elektro		CANTAS		Difference (%)	
Physical test						
Total length	2.5 m		3.2 m			
Total weight	7 kg		9 kg			
Specific weight	2.8 kg/m		2.8 kg/m			
Deflection	0.04 m		0.065 m		- 38%	
Cofg from bottom	0.81 m		1.40 m		- 42%	
Noise (dB)	69		79		- 12.7	
Temperature (deg C)	41		102		- 59.8	
Vibration test (m/s2)	P1	P2	P1	P2	P1	P2
	1.3	0.8	2.4	2.3	- 45.8	-65.2

VOLTAGE DEPLETION TEST OF THE BATTERY

Two batteries, which were denoted as Battery A and Battery B, were tested. Tests were conducted without a load in the laboratory and the actual voltage depletion test was performed in the field during the harvesting operation. The results of the tests listed in *Table 5* show that the average battery depletion rate was 1.16 V/hr and the average motor temperature was 38.8 °C over a testing period of 270 min. *Figure 5* shows the profiles of voltage depletion and motor temperature over time. The initial voltage of both batteries was 20.4 V and the value was reduced by approximately 5V by the end of the test. As for the motor temperature, it was fairly consistent throughout the test, with an average value below 40.0 °C, i.e., the normal operating temperature of the motor.

TABLE 5. Battery depletion rate (without load)

Battery	Initial voltage (V)	Final voltage (V)	Test duration (min)	Depletion rate (V/hr)	Average motor's temperature (°C)
Battery A	20.41	15.43	270	1.11	38.8
Battery B	20.38	14.91	270	1.22	38.8
Average	20.40	15.17	270	1.16	38.8



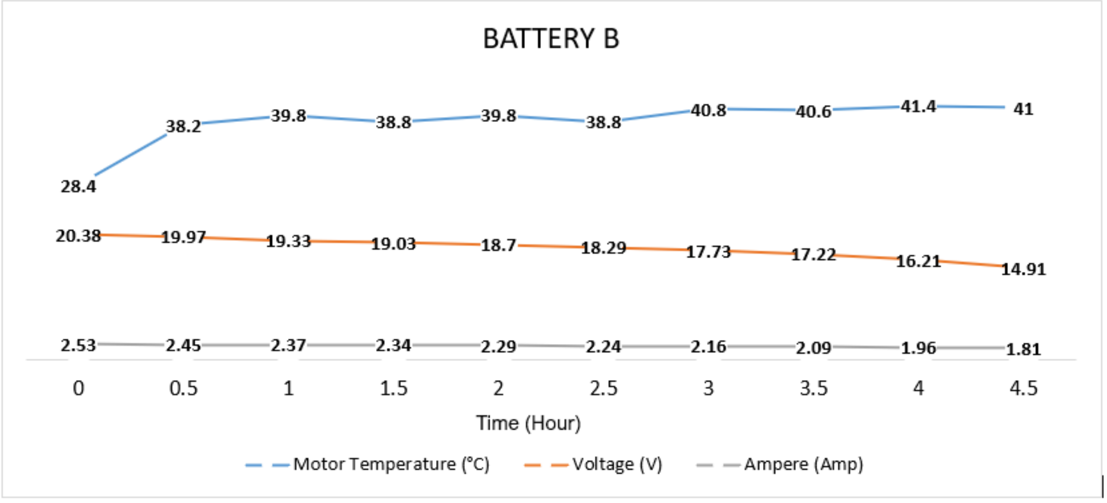


FIGURE 5. Battery Voltage and Motor Temperature against time

FUNCTIONAL TESTS

Based on the results of the functional tests shown in *Table 6*, it can be seen that the voltage levels for both batteries were identical at the time the functional tests ended. This indicates that the prototype was able to function as it was designed for, i.e., it can cut fronds and FFBs smoothly and efficiently. From a total of 38 palms attended, 94 fronds were cut and 31 FFBs were harvested within the total time required to accomplish the operation of 45 min. Thus, the harvesting performances were 0.85 palm/min and 0.67 FFB/min, respectively. From these performances, it was estimated that the harvesting performance of CANTAS Elektro would be 40 FFB/hr or 320 FFB/day for an eight-hour working period a day.

The average battery voltage depletion rate, which was measured with load in the field, was 1.93 V/hr. This value was 66.4% higher than that measured without load in the laboratory, which was 1.16 V/hr. The results also show that the power consumed during FFB harvesting was higher than that during frond pruning, which was 0.012 and 0.007 Volt/activity, respectively (see *Table 7*).

TABLE 6. Functional test of Cantas Elektro for harvesting ffb

	Initial battery voltage (V)	Total frond	Total FFB	Total palms	Total time taken (min)	Final battery voltage (V)	Battery depletion rate (V/hr)
Test 1	(min)	Final battery voltage	12	13	15	19.92	2.08
Test 2	(V)	Battery depletion rate	10	13	15	19.43	1.96
Test 3	(V/hr)	28	9	12	15	18.99	1.76
Total		94	31	38	45		
Average						19.44	1.93

TABLE 7. Performance of harvesting and pruning

Activity	Performance	Energy Requirement (V/Activity)
Harvesting	(0.52+0.49+0.44) / (31 FFB + 94 Frond)	0.012
Pruning	(0.46+0.44+0.47) / 186 Frond	0.007

FIELD EVALUATION

Table 8 shows the results of the field trial for CANTAS Elektro (marked as CTE1 and CTE2) and CANTAS (marked as C1 and C2). The machines were operated at full capacity for about five to seven hours per day. The results of the four-month trial (from January to April 2021) reveal that the average harvesting performances of CTE1 and CTE2 were 574 and 469 FFB/day, respectively, which were equivalent to 7.55 and 6.53 t/day, respectively (the average bunch weight was 14 kg). Therefore, the average performance of CANTAS Elektro was 7.04 t/day. The total hours of usage for the two CANTAS Elektro were about 100 to170 hours per month. In contrast, the harvesting productivities of C1 and C2 were 469 and 423 FFB/day, respectively, which were equal to 5.09 and 6.16 t/day, respectively. On average, the harvesting productivity of CANTAS was 5.62 t/day. It can be concluded that the harvesting productivity of CANTAS Elektro was 25.04% higher than that of CANTAS.

The power of the battery could last up to 2.5 hours on a single charge. Therefore, for an eight-hour working duration, the battery needs to be replaced three times so that the machine works efficiently.

It was also discovered that CANTAS Elektro required 33.8% lower repair and maintenance (R&M) costs during the four-month field trial. The R&M cost for CANTAS Elektro was RM1.57/t FFB, in comparison to RM2.37/t FFB for CANTAS.\

TABLE 8. results of field trial of CANTAS ELEKTRO VS CANTAS (JAN - APRIL 2021)

Machine type	Sample no	Description	Jan	Feb	Mac	Apr	Total	Avg
CANTAS Elektro (CTE)	CTE1	Total days	23	16	22	22	85	21.2
		Total hours	170	115	130	131	547	137
		FFB/month	16776	6812	10364	11718	45670	11417
		FFB/day	729	564	471	532		574
		Tonne/month	234	95	145	164		160
		Tonne/day	10.21	6.0	6.55	7.44		7.55
		Electrical cost (RM/month)						14.03
		R&M cost (RM/month)						246.92 (RM1.54/tonne)

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	CTE2	Total days	22	18	22	21	83	20.8
		Total hours	112	109	130	125	476	119
		FFB/month	8811	8590	10214	11219	38834	9708
		FFB/day	400	477	464	534		469
		Tonne/month	123	120	143	157		136
		Tonne/day	6.00	6.24	6.40	7.48		6.53
		Electrical cost (RM/month)						13.70
		R&M cost (RM/month)						216.88 (RM1.59/tonne)
CANTAS (C)	C1	Total days	20	23	24	22	89	23
		Total hours	88	103	106	98	395	99
		FFB/month	8005	9894	10325	9467	37691	9422
		FFB/day	400	430	430	432		423
		Tonne/month	112	138	144	132		131
		Tonne/day	5.6	6.0	6.0	6.0		5.09
		Petrol cost (RM/month)						
		R&M cost (RM/month)						305.33 (RM2.33/tonne)
	C2	Total days	20	18	22	21	81	20.2
		Total hours	,92	82	98	93	365	91
		FFB/month	8812	7926	9684	9245	35667	8916
		FFB/day	440	445	441	446		443
		Tonne/month	123	111	136	129		125
		Tonne/day	6.15	6,17	6.20	6.14		6.16
		Petrol cost (RM/month)						
		R&M cost (RM/month)						300.35 (RM2.40/tonne)

Note : average bunch weight : 14 kg

ECONOMIC ANALYSIS

COST EFFECTIVENESS

In the industry, the bottom line is the cost-effectiveness (CE) of the technology. The lower the CE, the more the technology will likely be adopted in the industry. The CE of the harvesting tool was calculated by dividing the purchase price of the tool by the total amount of FFB harvested throughout the tool's economic life (Stanner., 1992), as expressed in the following equation:

$$Cost\ effectiveness\ (CE) = \frac{Tool\ or\ machine\ price\ (RM)}{Total\ bunches\ harvested\ (tonne\ FFB)}$$

The unit prices of CANTAS Elektro and CANTAS at the time of the tests were RM5500 (including two units of batteries and one unit of battery charger) and RM3800, respectively. With a two-year economic life and 300 working days a year, the CE of CANTAS Elektro and CANTAS was calculated as follows:

$$CE\ of\ CANTAS\ Elektro = RM5{,}500 \div (7.04t\ FFB/day \times 300day/year \times 2yrs) = \mathbf{RM1.30/t\ FFB}$$

$$CE\ of\ CANTAS = RM3{,}800 \div (5.63t\frac{FFB}{day} \times \frac{300day}{year} \times 2yrs = \mathbf{RM1.13/t\ FFB}$$

It can be seen that the CE of CANTAS Elektro was 14.1% higher than that of CANTAS despite the former having higher harvesting productivity. This was because its unit price was higher than that of CANTAS. The CE of CANTAS Elektro can be reduced to RM0.89/t if its price is identical to that of CANTAS.

OPERATIONAL COST

Apart from improving the ergonomic factors of the machine, another reason for substituting the battery-powered machine for the engine-powered machine is the cost factor. This is due to the fact that electrical cost is much cheaper than the petrol cost. As for the economic analysis, the machine (CANTAS Elektro) was the fixed cost, while labour, electricity, repair and maintenance were the variable costs. The operating costs per tonne FFB (OPEX) for CANTAS Elektro and CANTAS were calculated using a straight-line depreciation method, which is presented in detail in *Table 9*.

The results of the economic analysis show that there was a significant reduction of 31.5% in the OPEX. CANTAS Elektro recorded only RM2.91 $t^{-1}day^{-1}$ FFB as compared to CANTAS, which recorded RM4.25 $t^{-1}day^{-1}$ FFB. The low repair cost was made possible because CANTAS Elektro experienced fewer breakdowns as compared to CANTAS. The total OPEX were RM6147/year and RM7160/year for CANTAS Elektro and CANTAS, respectively. As a result of this reduction, the estate will be able to save approximately RM1013 per machine annually. The OPEX of CANTAS Elektro of only RM2.91 t^{-1} FFB can be the deciding factor in the application of this technology in the estates.

TABLE 9. Cost analysis of Cantas Elektro *vs* Cantas using straight line depreciation method

	CANTAS Elektro		CANTAS	
CAPEX	RM5500		RM3800	
Average daily productivity	7.11 t FFB/day		5.62 t FFB/day	
Description	Calculation	Cost (RM/day)	Calculation	Cost (RM/day)
a) Depreciation (price/(life span x 300 days) OPEX	5500/(2 yrs x 300d)	RM9.16	3800/(2 yrs x 300d)	RM6.33
b) Electricity (Charging) / Petrol	0.216 kWh x 43.5sen/ kWh (TNB tariffs) 3 set battery @ 3 Hours Battery : Voltage : 36 V Current : 6.0Ah Charging time : 1 hrs Power (kWh) = 36V x 6.0Ah = 0.216kWh Power used per charging = 0.216kWh x 1 hrs = 0.216kWh	RM0.28 (Charging cost)	Petrol @ RM2.05/ltr x 1.5L/day	RM3.08 (Petrol cost)
c) Lubrication oil (2T)	-	-	RM38/liter x 0.03Ltr/day	RM1.14
d) R&M cost	(RM1.54/tonne + RM1.59/tonne)/2	RM1.57/tonne (RM11.05/day)	(RM2.33/tonne + RM2.4/tonne)/2	RM2.37/tonne (RM13.32/day)
Total OPEX (b + c + d)		RM20.49/day (RM6147/yr)		RM23.87/day (RM7160/yr)
OPEX (RM/t FFB)	(RM20.49/day)/ (7.04t/day)	RM2.91/t FFB	(RM23.87/day)/ (5.62t/day)	RM4.25/t FFB
e) Labour cost	7.04t/day x RM30/ t FFB	RM211.20/day	5.62t/day x RM30/ t FFB	RM157.80/day
TOTAL COST (a+b+c+d+e)		RM214.11/day		RM162.05/day
Cost per tonne = total cost/ productivity	(RM214.11/day)/ (7.04t/day)	RM30.41/t FFB	(RM162.05/day)/ (5.62t/day)	RM28.83/t FFB

BENEFITS TO WORKERS

In addition to easing the harvesting operation, the significant benefit that the workers gained from the use of CANTAS Elektro was the increase in their take-home pay by 29%, specifically from RM162.05/team/day or RM81/man-day by using CANTAS to RM214.11/team/day or RM107/man-day by using CANTAS Elektro. Therefore, the workers would have an extra income of about RM500 per month.

BENEFITS TO ESTATES

As for the estates' owners, several benefits could be gained through the use of CANTAS Elektro, such as the reduction in the number of workers and fringe benefit costs, namely housing, utility bills, paid medical leaves, as well as workers' welfare, which could amount to about RM10, 000/person/yr (Mei Mei Chu 2021).

The total hectarage of the trial plot for each machine (CANTAS Elektro and CANTAS) was 136 ha. The plots were located side by side, with similar topography, as well as palm variety and age. In the trial, CANTAS Elektro teams took on average 21 days to completely harvest the FFB in the designated plot, while CANTAS teams required 27 days. Therefore, the daily harvesting coverages were 6.44 and 5.01 ha/day/team for CANTAS Elektro and CANTAS, respectively (*Table 10*). Eventhough the the daily coverage of CANTAS Elektro was 22.2% bigger than that of CANTAS, the CANTAS Elektro teams were able to finish their harvesting operation six days earlier than the CANTAS teams.

TABLE 10. Harvesting coverage of Cantas Elektro Vs Cantas

	Total area (ha)	No of team	No of machine	No of workers	Total days required to complete 136 ha area	Daily coverage (ha/day/machine)
CANTAS Elektro	136	2	2	4	21	6.44
CANTAS	136	2	2	4	27	5.01
Different					- 6 days (-22.2%)	+ 1.43

DATA ANALYSIS AND RESEARCH FINDING

The data was examined to determine its quality and ensure that it was not out of the ordinary. The solid curve of the data histogram and frequency bars shown in *Figure 6* indicate that the data distribution was nearly normal, while the estimated process stability seemed to be consistent with the current harvesting process.

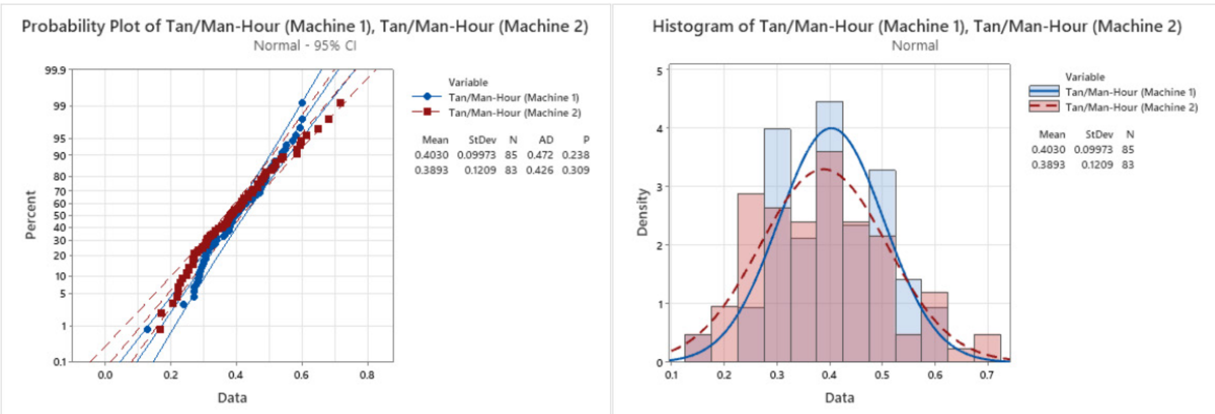

FIGURE 6. Probability and histogram estimate of the workers productivity

Figure 7 shows the box plot for the productivity of the machines in ton/man-hour. It can be observed that there was only a slight difference in the position of the data mean between the two machines. The average productivity of the second machine was 0.389309 tonne/man-hour whereas the average productivity of the first machine was 0.40302 tonne/man-hour.

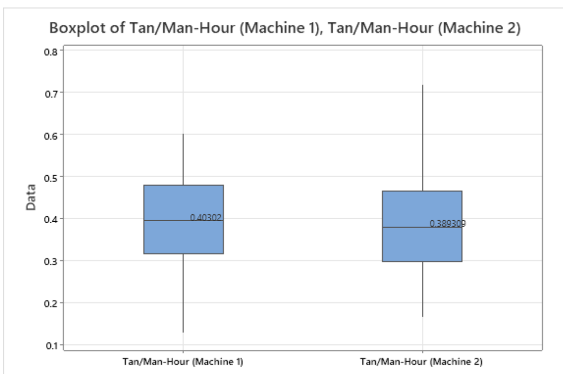

FIGURE 7. Box plots comparison of productivity by Cantas Elektro

CONCLUSION

In this work, a battery-powered CANTAS, which was known as CANTAS Elektro, was successfully designed, developed, and tested. Ergonomically, CANTAS Elektro was considered to be superior to its predecessor (CANTAS) as it produced lesser heat, noise, and vibration, in addition to being lighter than CANTAS. Thus, the harvesters could work more comfortably for long hours and improve their daily harvesting productivity. The outcome of the field trial conducted in a commercial estate proves that the use of CANTAS Elektro could increase harvesting productivity. It was found that the harvesting productivity of CANTAS Elektro was 26.5% higher than that of CANTAS, which greatly helped the harvesters to earn a higher daily income. In addition to easing the harvesting operation, the workers were able to increase their take-home pay by 29%.

As for the estates' owners, the use of CANTAS Elektro could offer several benefits, such as the reduction in the number of workers and fringe benefit costs. In addition, the daily harvesting coverage of CANTAS Elektro was 22.2% higher as compared to CANTAS, i.e., 6.44 ha/day/machine as compared to 5.01 ha/day/machine.

The introduction of CANTAS Elektro is expected to significantly impact the industry and the country by increasing harvesting productivity and workers' income, as well as reducing operational costs and the number of workers. This technology is highly advantageous as it is more ergonomic and environmentally friendly, cost-effective, emission-free, requires no petrol, and produces less noise and vibration. Moreover, the use of CANTAS Elektro will push the industry towards adopting green technology and sustainable palm oil industry.

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DECLARATION OF COMPETING INTEREST

None

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