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PERFORMANCE EVALUATION OF A TIPPING DEVICE FOR FRESH FRUIT BUNCH (FFB) LOADING

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ABSTRACT

Manual loading of oil palm fresh fruit bunches (FFB) involves picking up the bunches with an iron spike and dropping them into a bin or tractor-trailer. Workers need to repetitively lift a load above their shoulders hence, giving extreme strain to the muscle. To overcome this issue, a prototype was designed and developed to directly transfer FFB. The device is equipped with a hydraulic system and powered by a battery. There is a need to assess the overall performance of the device compared with the manual. The time taken to transfer a different number of bunches, time taken for total FFB evacuation, productivity and battery depletion rate was evaluated. Three-wheel transporters were used and a plot with medium-size FFB was selected. The study indicated that the device was able to handle 400 kg of loads in 38.1 s. It was found that by using the device, unloading activity will only consume about 4% of the total FFB collection time. The study showed that the machine helped the workers by reducing their time to complete the task by 35% more than the manual. In conclusion, the device functioned and performed as it is designed. Workers can now directly transfer the FFB into a bin at a reduced time.

Keywords: fresh fruit bunch, hydraulic powerpack, lifting device, oil palm, small transporter.

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INTRODUCTION

The economic performance of the Malaysian palm oil industry was very impressive with the value of palm oil exports of RM64.6 billion despite the Covid-19 pandemic situation in 2021 (Parveez *et al*., 2022). With a total oil palm planted area of 5.74 million hectares in 2021, the industry is facing difficulties to produce their optimum output due to the labour shortage, low level of mechanisation and escalating cost of fresh fruit bunches (FFB) production. The oil palm industry is very much dependent on labour. The lack of mechanisation options in plantations creates an over-reliance on manual labour for all key activities, especially harvesting.

The introduction of mini-tractors with trailers in the early 80s for in-field FFB collection was welcomed by the industries. Besides improving productivity and earnings, the mini-tractors also improved overall harvesting standards (Yaakob and Toh, 1988). The present manual loading system involves picking up the bunches with an iron spike and dropping them into a trailer that is pulled by a mini-tractor. Besides tractor-trailers, the use of 3 to 5 t lorries is also common in the industry. The average output of a mini-tractor per day is about 20 t FFB. The introduction of a mechanical loader (Grabber) in 1992 further improved the method for FFB collection (Ahmad and Ahmad, 1992). Among factors that were identified as critically influencing the efficiency of FFB evacuation process are the skills of the driver, terrain conditions, labour availability and harvesting technique (Mohd Lutfi and Hairul Rizad, 2020).

The introduction of a bin system in the oil palm plantations thereafter has given significant impacts on more efficient FFB collection and evacuation. Many plantations adopted this system and most of them integrated it with Mini-tractor Grabber with a high lift trailer. However, not all plantations are

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ready to accept this technology due to terrain and budget constrain, especially among field contractors and smallholders.

Besides mini-tractor, there are several small FFB transporters available for use in oil palm plantations. These machines are widely used and usually drop their loads on the ground at the collection point and the FFB will then be manually transferred into the bin or lorry (Azali *et al.*, 2015; Che Ahmad *et al.*, 2022). This multi handling activities also promote lower oil quality as damaged FBB will produce a higher percentage of free fatty acid (FFA) (Turner and Gillbanks, 2003).

Furthermore, these small FFB transporters are unable to be fully integrated with the bin system due to the limited tipping height. The average bin height is around 1.2 m to 1.8 m depending on the bin's size and this is far beyond the normal tipping height of small FFB transporters (about 0.3 m to 0.5 m). Though there are options such as the small FFB transporters to be fitted with a scissor lift or high pivot discharge mechanism to enable them to unload the FFB into the bin, these options are less favourable as they incur extra cost.

There are some cases where the use of a shallow bin is required when a small type of transporter is used. However, the load capacity is limited when this type of bin is in use. Another option is by using a bin with a door or gate system where the infield transporter can move to enter the bin to unload the FFB. The only drawback is that manual loading is still required when the bin is almost full as the transporter cannot move into the bin.

From ergonomic and bio-kinetic aspects, the current manual loading activities impose a risk of injury to the workers. Workers need to repetitively lift a load above their shoulders hence, giving extreme strain on the muscles and joints (Ng *et al.*, 2013; Nur Syazwani *et al.*, 2016). A large number of bunches will exhaust the workers by the end of the day. A solution is thus, needed to reduce these risks.

MATERIALS AND METHODS

Prototype Design and Development

Key considerations in the design process to develop the device were:

a) Mobile-type device for ease of mobility in the field
b) Able to lift and transfer the FFB into a bin, lorry or tractor-trailer (approximately 1.8 m height)
c) Can be attached to existing small transporter with minor modifications
d) Simple hydraulic lifting mechanism that could lift 400 kg loads (FFB)
e) Independent power source to run the system

The computer-aided-design (CAD) model of the device was done using the Autodesk Inventor software.

Time Taken to Complete One Operation Cycle with Different Number of Bunches

A study was carried out over six sets (5, 10, 15, 20, 25 and 30 bunches per load). The total weight for each set was recorded using a weighing bridge at the collection centre. Each set of bunches was placed in the device's bucket and times were recorded once the start button was pushed until all the FFB were transferred into the bin and the bucket frame was back to its standby position. Three replications per set were performed and the average value was recorded.

Duration for Total Operation

Using a three-wheel transporter with one driver and one helper, the duration for activities involving the use of the device was recorded, *i.e.*, the travelling time of the vehicle to search and collect FFB from the field and transport to the bin, time taken to unload FFB from vehicle to the tipping device and time taken for the tipping device to unload FFB into the bin and back to its standby position. Six replications were conducted and the average value was recorded.

Performance Comparison

Two units of three-wheel transporters were used to collect and transport the FFB from the field to the bin (one driver and one helper for each machine). One transporter was tasked to unload the FFB manually into the bin, while another one was tasked to unload the FFB using the device. The number of bunches and time taken to complete the overall loading task for both methods were recorded for 5 replicates. Medium-size FFB (12-15 kg per bunch) were selected from the same plot.

One-way analysis of variance (ANOVA) was used to determine the significant differences between the average time taken between the machine and the manual method. The value of the degree of freedom (DOF), F-statistic, and *P*-value were calculated. To determine the significant responses, values of F-statistic must be higher than F-critical in the distribution table, which is 3.55 at a 95% confidence interval. The F-critical value can be defined by referring to the f distribution table at a 95% of confidence level, *i.e.,* F0.05 (f1, f2). The numerator value, f1 is the degree of freedom of response, and the denominator, f2 is the deviation of DOF. F-statistic can be calculated using Equation (1):

$$F_{statistic} = \frac{Mean\ square,\ MS\ (between\ response)}{Mean\ square,\ MS\ (within\ response)} \qquad (1)$$

Battery Voltage Depletion

Depletion was calculated from the differences in voltage before and after each operation. The voltage of each battery was recorded before and after each operation using a digital multi-meter (20 replicates). The average load for each tipping operation was approximately 400 kg.

Operational Cost Analysis

A simple operational cost analysis was calculated using the straight-line depreciation formula.

RESULTS AND DISCUSSION

Prototype Design and Development

The body consists of two major components, *i.e.*, the mainframe and bucket frame. The mainframe was made from a combination of rectangular mild steel and designed to accommodate a bucket frame, hydraulic power pack, hydraulic cylinders, power source, tyres and towing system (*Figure 1*). The bucket frame was made from a combination of rectangular, plate and rod mild steel. It was designed for the temporary storage of about 400 kg FFB. The bucket frame was attached to two cylinders so that it can be pushed to 130° from the pivot points. This prototype was designed to service bins of up to 1.8 m in height. The hydraulic power pack system was powered by two units of 12 V lead-acid batteries that were connected in series. The technical specifications of the device are shown in *Table 1*.

TABLE 1. TECHNICAL SPECIFICATIONS OF A TIPPING DEVICE FOR FRESH FRUIT BUNCH (FFB) LOADING

Dimension, L x H x W (mm)	1980 x 1828 x 1370
Hydraulic power pack	Model: D222XXI DC 24V, 2.2kW 2600 RPM, 6.0 Nm
Working height (m)	1.8
Tyre size	5.00 -010 NHS 12 P.R
Battery	2 x 12V 1000 mAh

Proposed Working System (Three-wheeler transporter and bin system)

The tipping device will be attached to a transporter that will move to the bins in the field. These bins were placed strategically at points that were determined earlier. Thereafter, the device will be detached and placed at the side of the bin.

The operator/driver then starts his routine by collecting FFB in the field. Once fully loaded, the transporter will then manoeuvre to the bin to unload the FFB. The transporter will then unload the FFB into the bucket of the device in reverse position. Once completed, the transporter will then move forward (about 1-2 m from the device) and the device will lift the bucket to transfer the FFB into the bin (*Figure* 2) with a single press of a switch. The device will automatically retract to its original position once empty. The transporter will then immediately move back to the field, looking for more bunches without the need to wait and load the FFB manually.

Time Taken to Complete One Operation Cycle with Different Number of Bunches

A study showed that the prototype could lift up to 400 kg bunches in 38 s. The average time taken to complete one operation cycle was about 34-38 s depending on the number of loads (*Figure 3*). Longer time is needed to lift higher loads. This situation is normal due to the inability of the hydraulic motor/ pump to deliver sufficient flow to the hydraulic cylinders, especially when a battery is used as a power source for the hydraulic power pack.

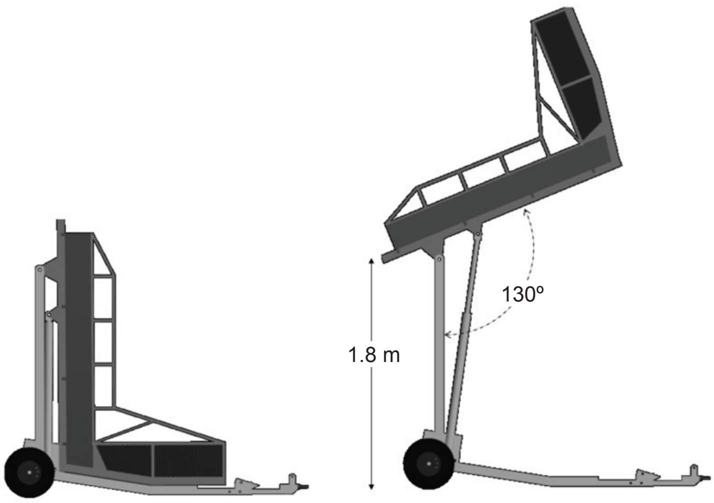

Figure 1. Side views of the device during standby and tipping positions.

Figure 2. Prototype in tipping position during a field test.

Duration for Total Operation

The average time taken to complete the total operation was about 315 s or 5.24 min (*Table 2*). By using the device, the FFB unloading activity only consumed about 4% of the total operation time. It was found that 88% of total operation time was consumed for travelling and searching for FFB. This is almost similar to the findings reported by Azmi (2000) and Turner and Gillbanks (2003), where the duration for travelling and picking FFB was around 77%-80% of the collection time. Hence, improvement through machinery enhancement and a better working system is thus necessary to speed up the FFB collection process.

Performance Comparison

A comparison study was conducted to compare the performance of the machine and manual loading. It was found that the average time taken for the machine to complete the loading task was shorter than manual loading. The machine performed better than the manual method as analysed by ANOVA through the calculation of time needed to complete the loading tasks (*Table 3*). F-critical was $F_{0.05}(1,8) = 5.318$ at a 95% confidence level ($\alpha = 0.05$). The F-statistic for the time responses is greater than F-critical with *P*-value lower than $\alpha = 0.05$. Thus, there is a significant difference between the means of time responses for both methods indicating that the machine indeed helped the operators by reducing their time to complete the task (35% faster).

A worker needs to repetitively lift the FFB above his shoulders with an iron spike and drop it into a 1.8 m height trailer in the manual method as opposed to the machine where the worker is required to only press the push button and the FFBs will be automatically transferred into the trailer. This is the biggest advantage of the machine besides consuming less energy to complete the task. However, it was found that a minimum loading activity was still involved in the process, especially when arranging FFB at the top layer of the bin. This arrangement of FFB is needed to maximise carrying the load and also to provide additional safety during transportation. It was also found that the total number of FFB that could be handled by using the machine was higher than in the manual method, 356 bunches and 320 bunches respectively.

TABLE 2. SUMMARY OF DURATION FOR TOTAL OPERATION

Activities	Time (s)	Percentage (%)
Travelling time for in-field transporter to search and collect FFB from field to bin	276.6 ± 24	87.9
Time to unload FFB from the machine to the tipping device	26.2 ± 1.1	8.3
Time for the tipping device to unload FBB into the bin and back to a ready position	11.9 ± 0.8	3.8
Total	314.7	100.0

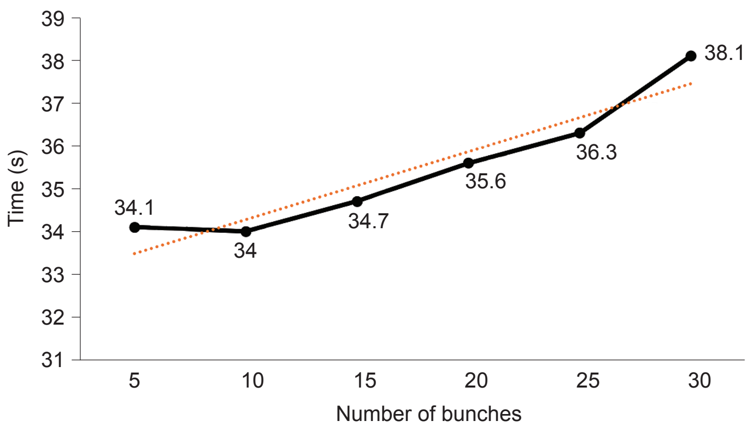

Figure 3. Time taken to complete one operation cycle with a different number of bunches.

TABLE 3. ONE-WAY ANOVA ANALYSIS OF TIME NEEDED TO COMPLETE THE LOADING TASK USING MACHINE AND MANUAL METHOD

Groups	Count	Sum	Average	Variance
Machine	5	1 710	342	1 252.5
Manual	5	2 310	462	256.5

Source of variation	SS	df	MS	F-statistic	*P*-value	F-critical
Between groups	36 000	1	36 000.0	47.71371769	0.000124	5.317655
Within groups	6 036	8	754.5			

Note: *F-statistic > F-critical = significant difference.

Battery Voltage Depletion

The device's battery depletion was about 0.02 ± 0.033 V per operation (*Table 4*). It was estimated that the battery can last up to two days of operation before it needs to be charged. However, this estimation varies depending on a daily usage, charging procedure, age and maintenance of the batteries.

TABLE 4. BATTERY DEPLETION PER OPERATION

Description	Voltage (v)
Battery depletion/operation (v)	0.02 ± 0.033

Operational Cost Analysis

Based on the estimated machine price of RM12 000, the economic life of 5 years, productivity of 25 t day^{-1}, labour cost of RM45 day^{-1}, 26 days working day a month and using the straight-line depreciation formula, the cost of using the machine is around RM2.26 t^{-1} FFB. With the expected labour saving of at least one person, the operational cost of the machine is thus justified.

CONCLUSION

A lifting device to assist FFB loading was developed and evaluated in the field. The concept of a mobile-type device using a simple hydraulic tipping mechanism is proven to be effective to accelerate the FFB loading operation. With the assistance of this device, workers can directly transfer the FFBs into a bin at a reduced time without exerting their energy excessively as only minimum manual loading activities were involved. It is envisaged that the technology could provide numerous advantages towards reducing labour requirements, providing better working conditions, and reducing multiple handling operations which in the end will lead to higher productivity.

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