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PARAMETRIC STUDY ON TRASH SEPARATION EFFICIENCY IN FRESH FRUIT BUNCHES (FFB) CONSIGNMENT

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ABSTRACT

Trash or contamination in oil palm fresh fruit bunches (FFB) is one of the major problems encountered by palm oil millers. Trash is commonly referred to as non-oil palm fruit matters, such as stones, sand, soil, mud, wood, grass, leaves and twigs, which are constituted in FFB consignments delivered to the mills. Trash is undesirable as it often causes choking, severe process machinery wear and tear and reduction in oil extraction rate (OER) due to the inclusion of trash weight. In this study, a vibrating trash separating machine prototype was developed locally to separate undesirable trash from FFB consignments. This study aimed to evaluate the performance of this prototype machine based on the total amount of trash removed from the FFB and loose fruits consignments. Three gap size configurations were studied, namely 45, 30 and 15 mm. The results showed that the prototype machine successfully removed trash from wet and dry FFB consignments with separation efficiencies of 80.95% and 91.91%, respectively. The best gap size between the rod bars was indicated by 15 mm. This prototype machine is expected to solve the contamination issue during palm oil milling process due to lack of efficient system to remove trash from the FFB consignments.

Keywords: contamination, efficiency, palm oil, separation, vibrating screen.

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INTRODUCTION

Malaysia is the second largest crude palm oil (CPO) producer in the world after Indonesia, accounting for about 40% of global oil production (Otieno *et al*., 2016; Parveez *et al.*, 2020). Oil palm cultivation areas in Malaysia have grown at a rate of 3%-5% annually (MPOB, 2012). The number of palm oil mills in Malaysia has increased significantly from 352 mills in 2001 to 451 mills in 2017 (MPOB, 2017). Palm oil mills located in East Malaysia increased from 30% in 2001 to 45% in 2017 due to oil palm cultivation area expansion. Malaysia also produces 18 million tonnes of CPO annually which is equivalent to 5.64 million hectares of cultivated area (Khaled *et al.*, 2018). Palm oil mill processes oil palm fresh fruit bunches (FFB) to produce two main products, namely CPO and palm kernel (PK). It is important for Malaysian palm oil mills to extract CPO and PK efficiently for commercial purposes.

In palm oil mill, it is of utmost concern that the presence of trash or contaminants in FFB consignments is one of the major problems encountered by palm oil millers. It has been reported that the loose fruits collected by in-field harvesters through handpicking and raking contain more than 30% trash (Ahmad *et al.*, 1995; Amirshah and Hoong, 2003; Darius and Fairulnizam, 2014). In fact, Shawaludin *et al.* (1996) emphasised that the trash content in sterilised fruits, also known as mass-passing-through-digester (MPD) has increased significantly from 6% in 1990-1991 to 11% in 1995-1996. This was contributed by the calyx leaves which

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comprised up to 33% of trash. The remaining 67% of trash consisted of sand, stones, mud and other plant materials. The trash including non-oil palm fruit matters, such as stones, sand, soil, mud, wood, grass, leaves and twigs, are often ignored by millers and other stakeholders (The Edge Markets, 2018).

Trash accumulated in FFB consignments causes problems during milling process. For example, the presence of excessive abrasive sand particles in the FFB will contribute to frequent process flow choking and excessive process machinery wear and tear, thereby increasing the operating and maintenance costs of critical machineries, such as digester, screw press, conveyor and centrifuge. In addition, stones and other objects in FFB can disrupt processing, which in turn reduces mill throughput effectively. Most importantly, trash also tends to absorb some part of the mesocarp oil, thus, reducing the efficiency of the oil extraction process (Badmus *et al.*, 2005). Consequently, it lowers the oil extraction rate (OER) of palm oil mill.

Recently, findings on the adverse effect of 3-monochloropropane-1, 2-diol (3-MCPD) esters as contaminants in refined palm oil have jeopardised the palm oil industry. It has been reported that the deodourising temperatures in refining process, pH level and chloride content in CPO production are the contributing factors to the 3-MCPD esters formation in refined palm oil (Ibrahim *et al.,* 2012; 2016). Nonetheless, there is no conclusive evidence to suggest that the source of chloride is actually originated from CPO. On the contrary, it may stem from the FFB consignment containing sand, soil and mud from the field. During harvesting, oil palm fruits that fall to the ground and FFB harvested tend to mix with the trash (sands, muds, leaves, fertiliser). Trash embedded in FFB is usually processed together during sterilisation process (*Figure 1*) as FFB cleaning before processing is not currently practiced at the mill. The use of chloride-containing fertiliser could also cause chloride contamination in FFB.

Figure 1. Trash mixed with oil palm bunches and loose fruits in a cage before sterilisation process.

Furthermore, there is limited equipment or system to remove trash efficiently during milling process such as sand catchers, de-stoners and de-sanders. Additional manpower is normally needed to address problems caused by extraneous objects in FFB. Although loose fruit collecting machine can reduce the trash amount, the acceptance of the use of this machine by planters is still low due to technical limitation and expensive cost (Khalid and Shuib, 2017). Ropandi and Zulkifli (2002) reported that the use of MPD washing system was able to remove sand and stone about 71.4% on average. With exclusion of stones, the removal percentage apparently reached as high as 93.0%, indicating an excellent and achievable target.

Moreover, FFB hopper was previously designed with slots on an inclined surface and equipped with a rail section to enable trash to pass through the gap. However, small fruitlets were discarded together with the trash, which required adjustment in the size of the openings to achieve effective separation. Nevertheless, high construction and maintenance cost, frequent hopper gap clogging and high loss of small loose fruits resulted in poor and outdated design. In current milling practice, the segregation and removal of trash are carried out by slotting one of the FFB conveyors as shown in *Figure 2*. FFB and trash pass through without an efficient mechanical separation system. As a result, the quantity of trash removal is about 60-80 kg per day or less. Meanwhile, *Figure 3* shows the previous design of oil palm fruit screening developed by Badmus *et al.* (2005).

Currently, palm oil mills are designed to remove trash progressively during processing via crude oil de-sander, dilution tank, vertical clarifier tank, continuous settling tank, nut polishing drum, de-stoner, sludge separator and decanter. With the presence of trash, the machinery damage in the processing line is inevitable. Thus, it is critically needed to remove trash at the initial processing stages to prevent excessive wear and tear to the processing machinery by addressing the root cause of the problem. To date, the segregation of trash from FFB consignment has not been well practiced in palm oil mills. It is necessary to improve separation efficiency by installing an efficient mechanical separation system. Thus, this study is aimed to highlight the development of a vibrating trash separator machine (TSM) as a prototype to remove trash from the FFB consignment prior to milling process.

In this study, the performance of the prototype machine was evaluated based on total amount of trash removed from the loose fruits and FFB consignments through the difference of gap sizes between the rod bars. The screening design was made based on the trash size so that appropriate openings for trash aperture can be obtained. Trash can be divided into various sizes based on minimum loose fruit size to force the particles through a specific screen size (Enrique *et al*., 2005). The best gap size between the rod bars was determined based on trash removal efficiency of dry and wet FFB consignments, and loss of loose fruits. This study is expected to promote good milling practices in maintaining uncontaminated FFB consignment and provide better trash management in palm oil mills.

Figure 2. Separation unit at FFB conveyor for trash removal.

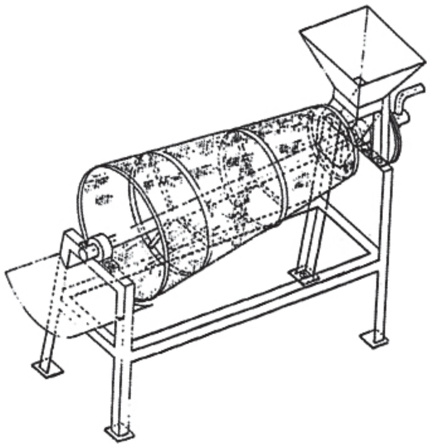


Figure 3. Oil palm fruit screening machine.

MATERIALS AND METHODS

Trash Separator Machine (TSM) Prototype

A prototype for an industrial vibrating TSM was developed to meet the actual palm oil mill operation, which included a pre-cleaning system to remove trash from FFB consignments. This TSM was constructed and installed without altering the current milling operation. It was used to reduce the weight of FFB processed by removing trash from the initial processing stage as pre-cleaning system. The designed TSM components consisted of sieve, shafts, pulley (for shaft and electric motor), bearing, belt, spring, electric motor and support.

The TSM was also designed to separate non-oil palm fruit matters from FFB consignments such as sands, soil, mud, stones and leaves. *Figure 4* illustrates the schematic diagram of TSM with 2100 mm width and 4572 mm length. *Figure 5* illustrates the prototype of the vibrating TSM. The bars were made of mild steel with various cross-sectional profiles. Round and hollow cross-section rod bars were installed as each bar was mounted individually onto the transverse beam. The vibrating sieve was equipped with 25 mm diameter springs on the side of the vibrating sieve unit. The unit was also configured with high frequency and 30 kW electric motor unit.

Materials

FFB samples consisting of loose fruits and trash were obtained from a nearby plantation in Teluk Intan, Perak, Malaysia. Most of the collected samples were of the *Tenera* species; a crossbreed clone between *Dura* and *Pisifera* which has 30% more mesocarp for high oil production (Babu *et al*., 2017). FFB and loose fruits received were from three maturity phases, namely unripe, underripe and ripe. The ripeness standard was determined based on the grading method developed by Malaysian Palm Oil Board (MPOB, 2016).

To represent dry consignment, the FFB and loose fruit samples were collected randomly on sunny days (not raining the previous day), while the wet consignment was represented by samples collected on rainy days. The FFB consignments comprised of oil palm bunches, loose fruits and trash, weighing in the range of 1000-1500 kg. These consignments were used in this study to evaluate the efficiency of the developed TSM for trash removal.

In addition, a total of 100 kg contaminated loose fruits samples was also collected from the plantation using rake and hand-picked. These samples were used to determine the best gap size to retain loose fruits from being removed with trash. Contaminated loose fruit samples were sorted manually into only trash and only loose fruits, and then weighed. Based on the weight of the sorted trash and loose fruits, the best gap size was determined.

Performance Evaluation of TSM

The performance of the TSM was evaluated in terms of trash separation efficiency and capacity by considering two parameters. The trash separation efficiency of this study was based on actual on-going and periodic measurements. The first parameter studied was the variation of the gap size between the bar rods of the TSM to allow trash to pass through the system, and the second parameter was to obtain the best gap size for high separation efficiency of dry and wet FFB consignments.

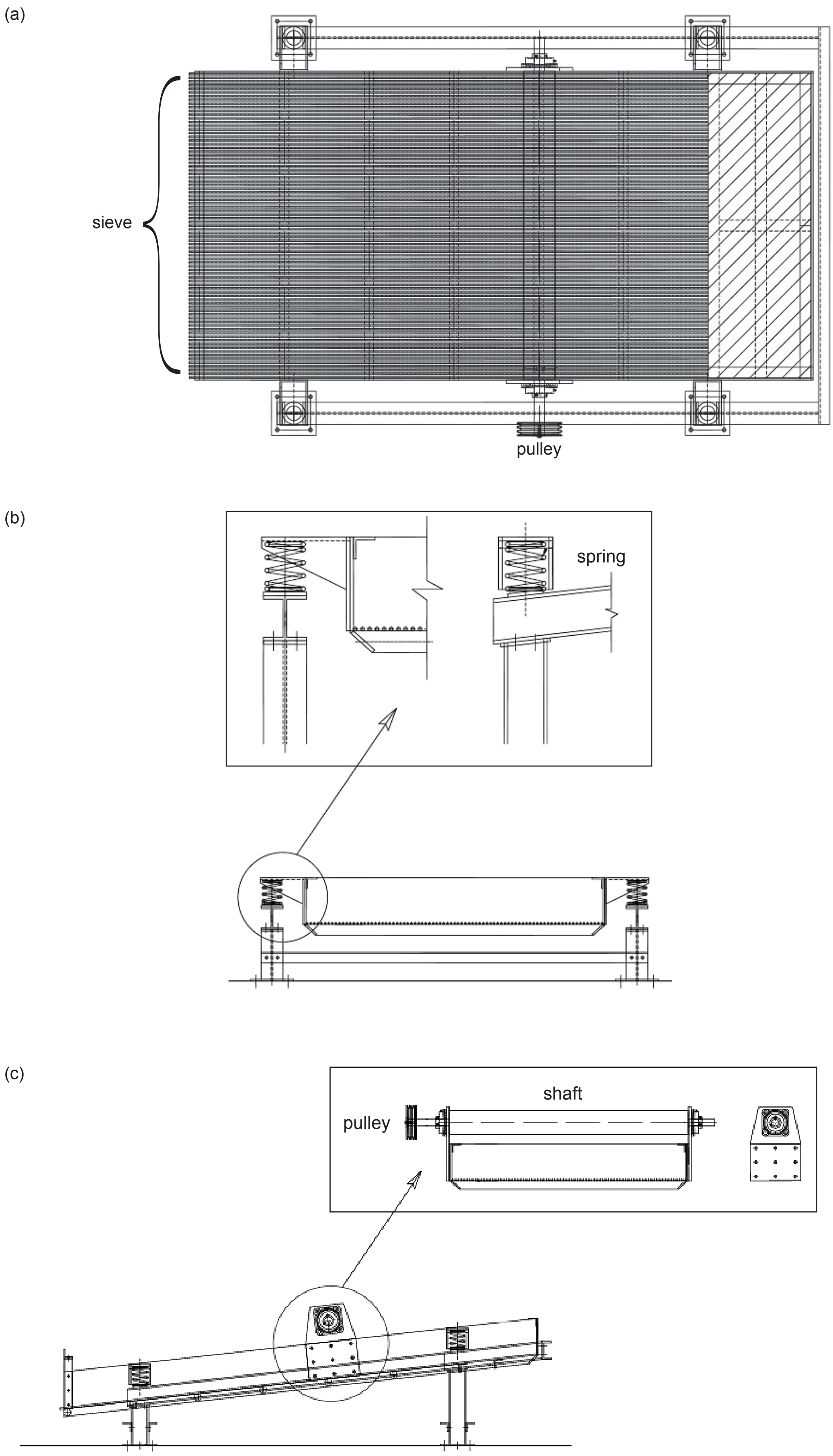


Figure 4. Schematic diagram of vibrating TSM (a) top view, (b) front view and (c) side view.

Figure 5. Prototype of vibrating TSM.

Determination on Effect of Different Gap Size

The TSM feed was fitted with various sizes of loose fruits and trash. About 100 kg of contaminated loose fruits consignment passed through the TSM to remove sand, stone, vegetative matters and other trash. The TSM was also tested for its efficiency to remove maximum amount of trash. Three different gap sizes of 45 mm, 30 mm and 15 mm were investigated for trash separation from the loose fruit consignments. The largest gap size of 45 mm was selected which corresponded to the thresher drum slot size of 46 mm (Leang, 2011). The thresher drum serves to remove sterilised oil palm fruitlets from the bunches during the milling process.

Selection of the gap size was based on the average diameter and length of oil palm fruitlets. The average diameter and length of oil palm fruitlets are between 18 to 25 mm and 35 to 40 mm, respectively (Basyuni *et al*., 2017). The separation gap size between the rod bars was correlated to the smallest loose fruit size to minimise loss of fruitlets during the separation process. The gap size was reduced from 45 mm to a minimum size of 15 mm to investigate the efficiency of the separation process. The smallest gap size selected was 15 mm due to manufacturing constraint and availability. Six repetitions were performed to variations in gap size for loose fruit consignments.

Determination on Trash Separation Efficiency of Dry and Wet FFB Consignment

Figure 6 illustrates the separation process flow of the TSM to remove contaminants from the FFB consignments. The consignments consisting of loose fruits and trash as received from nearby plantation were weighed and unloaded from the lorry onto the loading ramp at the mill. Then, the dry or wet FFB consignment was subjected to separation process by passing through the TSM, which served as a pre-cleaning system to remove sand, stone and old loose fruits prior to processing to ensure maximum trash removal.

The TSM was fixed at an inclination of 15° to allow smooth flow of FFB through the sieve under gravitational effect. It was found that at lower inclination degree (less than 15°), the FFB flow was halted causing backlog of bunches at the entry to the TSM. At inclination degrees higher than 15°, FFB was separated smoothly but the removal of trash was not efficient. This could be due to short retention time for the FFB to pass through the TSM.

In this study, it was assumed that the loss of loose fruits together with trash did not occur to facilitate the measurement of the separation efficiency of trash from the FFB consignment. Separation efficiency, (S_e) is defined as the ratio of the amount of trash separated by the TSM screening to the amount of trash to be separated loaded into the TSM screening. Constant trash weight was added manually to the FFB consignment before being fed into the TSM. The trash removed from the TSM was collected, analysed and quantified. The calculation of S_e of dry and wet consignments is shown in Equation (1).

$$S_e = \frac{Weight\ of\ trash\ separated}{Weight\ of\ trash\ added} \times 100 \qquad \text{Equation (1)}$$

Statistical Analysis

Data for mean, separation efficiency, standard deviation, standard error and confidence intervals were analysed statistically using Microsoft Excel. The paired *t*-test as expressed in Equation (2) was used to test for significant difference between the amounts of trash separated in the two consignment conditions (*i.e.*, dry and wet) studied.

$$t = \frac{d}{s\sqrt{1/n}} \qquad \text{Equation (2)}$$

where,
d = average difference in weights of trash separated between two conditions
s = standard deviation
n = sample population

The mean weight of trash was calculated by Equation (3):

$$x = \frac{\Sigma xi}{N} \qquad \text{Equation (3)}$$

where,
Σxi = sum of trash weight
N = number of trial sample

RESULTS AND DISCUSSION

Trash Contamination in FFB Consignment

Trash contamination in FFB consignment is categorised as trash embedded in FFB and trash mixed with loose fruits (*Figure 7a*). Trash embedded in FFB could be due to the impact when fruit bunches fall to the ground during harvesting. *Figure 7b* illustrates trash mixed with loose fruits during on-site collection and transportation.

Effect of Different Gap Sizes

The effect of gap sizes on trash separation efficiency with loose fruit consignment is summarised in *Table 1*. During the observation, trash was sent to the palm oil mill together with loose fruits consignment containing high amount of sand, soil, mud, stones and vegetative matter. In fact, most of them were in the form of calyx leaves as shown in *Figure 8*. *Table 1* indicates the performance of the

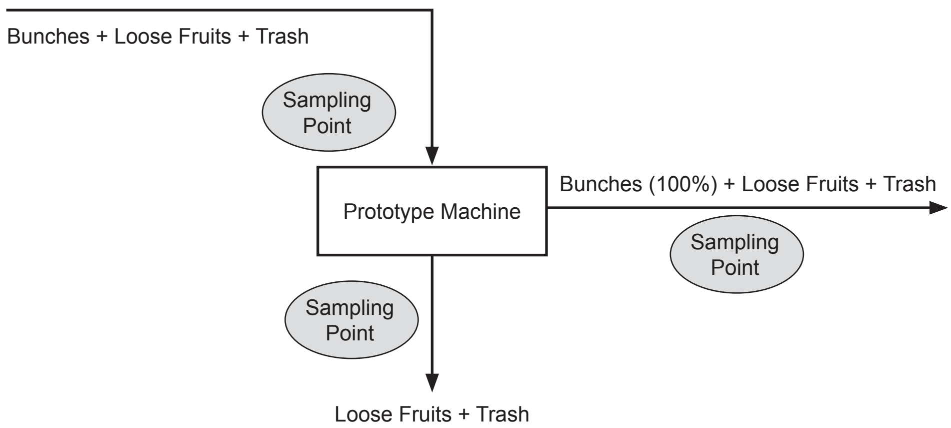


Figure 6. Process flow to separate trash from FFB consignment.

Figure 7. Trash mixed with (a) FFB and (b) loose fruits.

separation process for the TSM. It can be observed that as the gap size decreased, the separation efficiency improved. The amount of trash passing through the screen as well as the amount of loose fruits carried over into the trash consignment with different gap sizes of rod bars were recorded.

Figure 8. Non-oil palm fruit matter collected after screening.

More trash was removed at a gap size of 45 mm between the rod bars. The average amount of trash that can be removed was about 35.03 ± 1.09 kg and suffered high loss of loose fruits carried over with trash. The amounts of trash removed for 30 mm and 15 mm gap sizes were about 17.86 ± 1.66 kg and 6.46 ± 1.29 kg, respectively. The amount of trash weighed included the weight of loose fruits removed together with trash during screening. Each gap size was tested six times with different loose fruit consignments to ensure different loose fruits and trash sizes passed through the TSM during screening.

The amount of trash removed decreased as the gap size between the rod bars decreased from 45 to 15 mm. It was also observed that the separation efficiency for removing trash from loose fruits increased when less loose fruits were carried over during screening. This may be influenced by the decreasing gap size between the rod bars.

Due to various trash sizes of present in loose fruit consignments, TSM screening was developed with small gap sizes to allow small stones, grass, twigs and sand to pass through. This is in agreement with Davies (2012) who reported that the geometric and arithmetic mean diameters of loose fruits ranged from 21.36 to 29.23 mm and 20.80 to 27.80 mm, respectively.

However, such design also allowed some loose fruits to pass through which resulted in high losses to palm oil mill. Therefore, the recovery of loose fruits is prioritised to remove trash optimally at this stage. Loose fruit recovery is a critical factor as loose fruits come from the outer layer of FFB and account for up to 50% of total percentage of oil to bunch (Gan *et al.*, 1995).

Trash Separation Efficiency on Dry and Wet FFB Consignment

Separation efficiency for removal of non-oil palm fruit matter in dry and wet FFB consignments is shown in *Table 2*. A paired *t*-test was performed to analyse the resulting trash weights separated for both consignment conditions. The results indicated that there was no significant difference between the two sets of FFB consignments (wet and dry). There was a tendency towards a decreasing trend of separation efficiency for dry and wet FFB consignments.

TABLE 1. EFFECT OF GAP SIZES ON TRASH SEPARATION PERFORMANCE

	Gap size		
	45 mm	**30 mm**	**15 mm**
Weight of sample (kg)	100	100	100
Mean weight of trash removed (kg)	35.03	17.86	6.46
Standard deviation, S_d	1.09	1.66	1.29
Observations	Contained many loose fruits in various sizes	Contained some loose fruits in various sizes	Contained few loose fruits

TABLE 2. SUMMARY OF TRASH SEPARATION EFFICIENCY OF DRY AND WET FFB CONSIGNMENT

	Dry FFB consignment			Wet FFB consignment		
Weight of FFB consignment (kg)	500	550	600	500	550	600
Weight of trash added (kg)	40	50	60	60	50	40
Weight of trash removed (kg)	36.51	45.88	55.63	48.81	40.29	32.37
Trash separation efficiency (%)	91.28	91.76	92.72	81.35	80.58	80.93

For dry consignment, the separation efficiency ranged from 91.28% to 92.72%, while the separation efficiency for wet consignment ranged from 80.58% to 81.35%. The highest separation efficiency (92.72%) was obtained at 600 kg dry consignment, while the lowest efficiency (80.58%) was obtained at 550 kg for slightly wet consignment. Separation efficiency decreased by 12.14% depending on the consignment conditions.

The wet consignment was affected by rain and this condition made the trash more sticky and easily embedded in the FFB. Rain water can also increase the moisture content of FFB and reduce the quality of CPO (Ayat *et al.*, 2009). This complicated the process of removing trash from the FFB consignment, especially after rainy days. The vibration mechanism integrated in the TSM forced the mud to detach from the FFB which resulted in high separation efficiency achievable for both conditions (wet and dry). Thus, it can be inferred that the TSM was able to separate trash with efficiency of more than 80%.

Referring to *Table 2*, the results also revealed that the TSM was able to achieve an average separation efficiency of 91.91 ± 0.73% for trash removal for dry consignment. The average trash removal separation efficiency for wet consignment decreased slightly to 80.95 ± 0.39%. A similar study by Badmus *et al.* (2005) showed that calyx can be removed from oil palm fruits after threshing with separation efficiencies of 82% and 96% for wet and dry consignments, respectively.

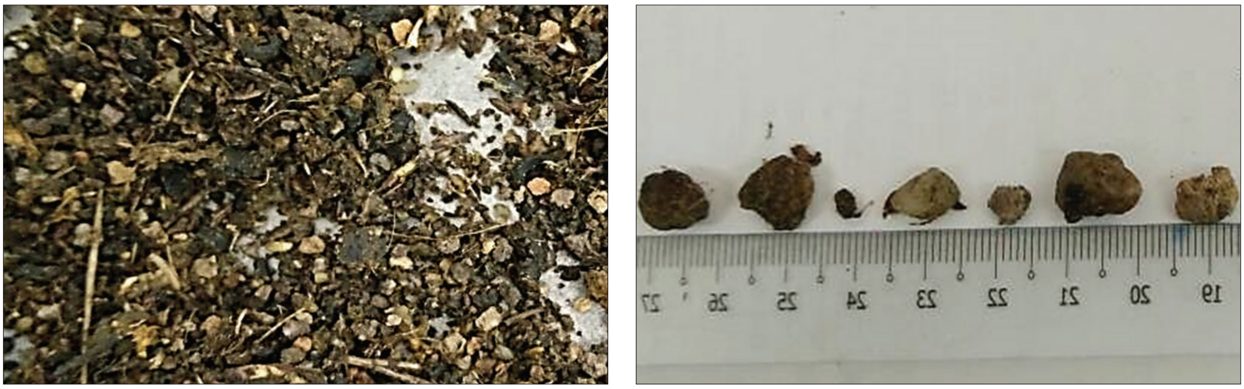
Results showed that the FFB consignment conditions (dry or wet) had an influence on the separation efficiency. Wet trash, such as sand and soil embedded in the bunch in the form of mud, absorbed more water and sticked to the FFB. Such trash was difficult to separate or remove. This is in agreement with Folami *et al.* (2016) who also found that the separation efficiency was low for rice processing machine as the feeding material has high moisture content. Similar results were also reported by Firouzi *et al.* (2010) where the performance of rubber roll husker decreased as the moisture content of paddy increased.

Performance Evaluation of TSM

Trash removal efficiency of 1000 kg FFB consignment is summarised in *Table 3*. The results obtained in this study were based on the actual process that was on-going with the gap size of 15 mm and fixed inclination of 15^{o} installed at the palm oil mill. The trials were repeated with 15 samples of FFB consignment samples for each condition. From *Table 3*, the relationship between separation efficiency, and wet and dry consignments was observed. The collected of trash after TSM as shown in *Figure 9.* The results showed that wet consignment has lower separation efficiency compared to dry consignment. This TSM was able to remove trash from dry consignment as much as 7.63 ± 0.70 kg from 1000 kg dry consignment. The results of this study also showed that 95% confidence intervals for trash removal ranged from 6.26 kg to 8.99 kg. Meanwhile, trash removed from wet consignment was 5.50 ± 0.45 kg per 1000 kg FFB with trash removed from wet consignment recorded 95% confidence interval ranging from 4.62 kg to 6.38 kg.

Stone removal is important for the mill to reduce machine wear and tear during processing. *Table 4* summarises the amounts of small stones that were removed during the trial. This indicated that about 0.37-0.53 kg of small stones were removed using the TSM for each tonne of FFB (*Figure 10*) which was approximately equivalent to 5.86%-7.49% of the total trash removed. The remaining 92.51%-94.14% of trash consisted of sand, mud and vegetative matter. Normally, mill processes FFB around 500-1000 t of FFB per day based on the mill capacity. Hence, the result shown that for 1000 t of FFB consignment processed was contained about 435.84 kg of small stones that can affect the machine wear and tear during processing.

Figure 9. Foreign material and trash collected after separation process of TSM.



(a) (b)

Figure 10. (a) Stones and (b) sizes of stones collected after separation by TSM.

TABLE 3. ANALYSIS FOR 1000 KG FFB FED TO TRASH SEPARATION MACHINE

Type of feed	Weight (kg)				
	FFB	Mean	S_d	S_{err}	95% CI
Dry	1 000	7.63	0.70	0.18	6.26 - 8.99
Slightly wet	1 000	5.50	0.45	0.12	4.62 - 6.38

Note: S_d - standard deviation; S_{err} - standard error; CI - confidence intervals.

TABLE 4. QUANTITY OF STONES IN FFB DELIVERED TO PALM OIL MILL

Trial	FFB passed through (t)	Small stone removed (kg)	FFB (kg t^{-1})
1	200	75.08	0.370
2	200	106.26	0.530
3	200	84.94	0.420
4	200	90.82	0.450
5	200	78.74	0.390
Total	1 000	435.84	-

During separation of trash, mud from wet consignment tended to accumulate on the TSM rods. This affected the separation efficiency owing to the reduction of space between the rod bars to remove the trash. The efficiency of physical separation depends on various parameters such as moisture content, clay content, humid content, particle shape and size distribution (Balasubramaniam, 2017; USEPA, 1995; Williford *et al.*, 2000). These parameters should be taken into account when attempting to predict screening performance.

This study also found that the fruitlets were prone to bruising during screening as the FFB collided with the conveyor prior to screening. Previous studies have postulated that free fatty acid (FFA) may increase with bruising levels rather than time delay between bruising and oil production (Che Rahmat *et al.*, 2018; Hadi *et al.*, 2009). In addition, Rasli *et al.* (2019) deduced that crop parameters and loading orientation affect the rupture force and energy of oil palm fruitlets which decrease with ripeness.

It is expected that this innovation will boost the efficiency of CPO production and increase the OER of palm oil mill by reducing the weight of FFB processed. It can also solve the oil production and quality problems by removing trash and preventing wear and tear of machinery at the initial stage of the milling process.

CONCLUSION

This study demonstrated the capability of vibrating TSM to remove significant amount of trash prior to milling process. The results of this study concluded that the efficiency of the TSM to remove trash from the wet FFB consignment was lower than that of dry consignment. The gap size of 15 mm was found to be able to remove trash from dry and slightly wet FFB consignments with average separation efficiencies of 91.91% and 80.95%, respectively, with minimum loss of loose fruits. This TSM can benefit palm oil millers in terms of weight reduction between 5.50-7.63 kg per 1000 kg FFB consignment processed. The deduction of contaminant weight from total amount of FFB processed will consequently increase the OER. Better oil recovery is also expected as oil losses normally absorbed by foreign vegetative materials have been minimised. The vibrating TSM performance showed that the screening can be utilised by palm oil millers as a pre-cleaning system for their initial processing stage. Moreover, the machinery wear and tear can be reduced by preventing trash from entering the processing line.

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