Factors Contributing to Oil Losses in Crude Palm Oil Production Process in Malaysia: A Review

Ummi Kalsum Hasanah Mohd Nadzim[a], Robiah Yunus[b,c,*], Rozita Omar[b], Bo Yuan Lim[a]

[a]Institute of Advanced Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[b]Department of Chemical and Environmental Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[c]Insititute of Plantation Studies (IKP), Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.

Abstract

One of the key performance indicators of the palm oil mill is the oil extraction rate (OER), indicating the amount of oil that can be extracted from the fresh fruit bunches (FFB). The OER currently fluctuates throughout the years. Thus, this paper reviews the technical factors contributing to the fluctuation of OER in terms of oil losses in the crude palm oil (CPO) production process in Malaysia. The sources of oil losses could be attributed to oil palm planting materials, loose fruits, ripe bunches and unstripped bunches (USB) and prevention actions have been reported by several researchers. High oil losses also occur at the waste streams during processing, such as steriliser condensate, pressed mesocarp fibre and sludge from clarification process.

Moreover, oil losses have a significant impact on CPO revenue. The future outlook of Malaysian CPO is promising for CPO export, import and revenue in the year 2020 due to the implementation of biodiesel (B7, B10 and B20) in the industrial and transport sectors. All relevant parties in the palm oil industry should understand the factors contributing to oil losses for necessary actions taken to improve OER and reduce oil losses as well as achieve a sustainable palm oil industry.

Keywords; palm oil, oil loss, oil extraction rate, sustainable

Introduction

Malaysia had its first cultivation of oil palm in 1917 [1]-[2], with initial slow growth. However, plantation development accelerated through large-scale investments in the cultivation of oil palm for the last 50 years [2]. Oil palm plantation in Malaysia has increased from 5.74 million hectares in 2016 to 5.81 million hectares in 2017 [3]. This industry is an export-oriented industry, where about 90% of total production depends heavily on the world market, while merely 10% is for local consumption [4]. In 2017, crude palm oil production increased by 15.0% to 19.92 million tonnes compared to 17.32 million tonnes in the previous year [5]. Total export revenue from oil palm products remarkably increased by 14.62% to RM 77.85 billion in 2017 compared to RM 67.92 billion achieved in 2016 due to higher export volume and better prices [6].

The accelerating palm oil production is aligned with substantial demand and economic benefits to the country. Sustainable development should be implemented in the palm oil industry by improving the palm oil production process, incorporating new and efficient technologies, measuring solid environmental and social policy and involving stakeholders. This also includes the establishment of Malaysian Sustainable Palm Oil (MSPO), an initiative from the palm oil industry players and the Malaysian government through the Ministry of Primary Industries. The objective of MSPO is to address sustainability issues and challenges which are related to the multi-stakeholders involved in the industry in complying with Malaysian laws and international agreements. There is a need for sustainable production throughout the supply chain, starting from raw materials until transported to the consumer. The MSPO encourages smallholders to establish, maintain and improve their operational practices within a management system framework towards achieving sustainable production of palm oil [7].

For the last 20 years, the performance of the oil extraction rate (OER) in Malaysia went up and down tremendously. The national average of OER in Malaysia from 1980 until 2002, had fluctuated from a low of 18.5% in 1982 to a high of 19.9% in 1987 to 1988. However, many individual mills had successfully obtained more than 20% OER [8]. In recent years, the OER still depicted the fluctuating trend from 20.25% in 2013 to 20.18% in 2016, then it declined to 19.72% in 2017 [9]. One of the key performance indicators of this industry is the OER that indicates the amount of oil that can be extracted from the fresh fruit bunches (FFB). According to Chang et al. [8], to evaluate the potential gain/loss in terms of CPO quantity and value in the following year, OER records for the past ten years are used to determine the annual change of OER in the previous years. The differentials of annual OER and 20% OER benchmark are used to estimate the loss in revenue. Low OER signifies low oil productivity and revenue, and some oil losses may also occur during a particular processing stage [8],[10], making our palm oil industry unsustainable and uncompetitive in the market. In improving the OER and reduce oil loss, the predominant causes must be identified beforehand. This paper intends to give reviews and understanding of the factors that contribute to oil losses in the palm oil production process, which may reduce oil extraction rates, which are crucial to be solved by the millers and industry players. The impact of oil loss on the CPO revenue is also included in this paper.

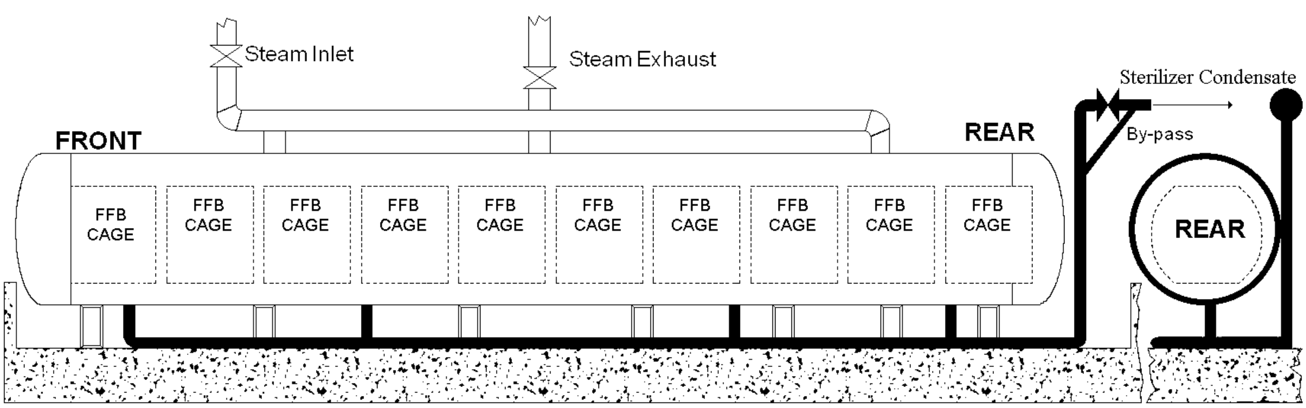
*Corresponding author.
E-mail address : robiah@upm.edu.my

Conventional Palm Oil Milling Process

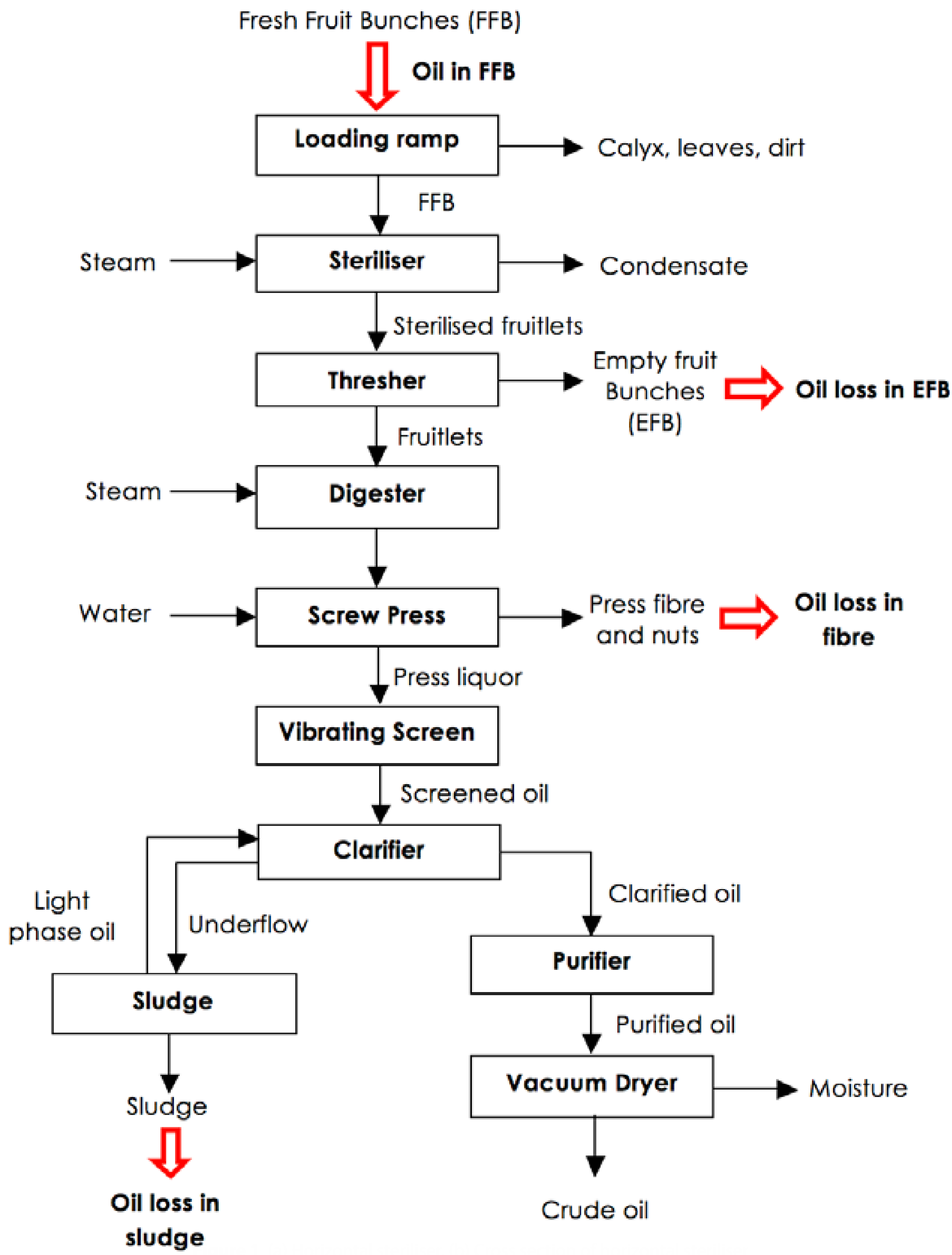
In conventional palm oil milling process, the FFBs are sterilised using saturated steam at a pressure of 40-45 psi, and temperature of 131-140°C for 60-90 minutes [11]-[13]. The sterilisation process is typically carried out in a horizontal cylindrical vessel (Figure 1). It is operated either as single-peak, double-peak or triple-peak as batch process pressure pattern. The peaks indicate the heat distribution coming from the steam to sterilise the FFBs. The purposes of the sterilisation process are to deactivate the lipase enzyme inhibiting free fatty acids formation and facilitate carbohydrate hydrolysis to detach fruits from the bunches [14]-[15]. This is the crucial stage that determines the maximum oil recovery.

After sterilisation, the sterilised fruitlets are separated from the bunch in a rotating drum thresher, and these fruitlets are reheated and agitated in a steam-heated vessel, or known as digester, to loosen the mesocarp. Subsequently, the mesocarp is pressed using a screw press, producing oil, water, and non-oily solids, together with fibre and nuts. The press liquor is subjected to the clarification process to remove debris, fibrous materials, and non-oily solids. A large amount of hot water is added as dilution during this process to facilitate the separation of oil and sludge due to density differences. The oil is then purified and dried to produce crude palm oil (CPO), while water and solid impurities are discharged as palm oil mill effluent (POME). Figure 2 illustrates the potential sources of oil losses in the palm oil milling process.

(a)



(b)



\

Figure 2 A flow diagram of the palm oil milling process and potential sources of oil losses

Sources and Prevention of Oil Losses

The conventional palm oil milling process is known to be accountable for the oil losses in the palm oil production process. Hasan et al. [16] listed several sources of oil losses in palm oil mill, namely empty fruit bunches after threshing, press cake fibre from screw press, steriliser condensate, sludge from the separator and unstripped bunches (USB) after threshing. The occurrence of oil losses may influence by inefficient machinery, poor maintenance programme and leakage (by breakdown or overflow of tanks) [17], as well as the use of ineffective processing variables [18]. Other factors that also affect the OER can be either from the fruit bunch composition and geometry, planting materials, climatic variations, and inefficient management of ripeness standard and harvesting, loose fruit collection or inadequate labour force [8].

Therefore, a comprehensive study should be carried out to explore the predominant factors that potentially contribute to the oil losses in the palm oil milling process covering planting materials, machinery adopted in the mill and process control management.

Oil palm planting materials

The planting material has a significant influence on the FFB quality [19]. The oil palm fruits in Malaysia are mainly divided into three generic forms: *Dura*, *Pisifera* and *Tenera*. The hybrid of *Dura* and *Pisifera* (DxP) produces *Tenera* variety that has high mesocarp oil content and becomes the basis of modern plantation and commercial oil palm today [20]. The differences between these three types of fruits are due to their size of mesocarp and shell (Figure 3). The *Dura* variety has a distinctive thick shell and thinner mesocarp, while the mesocarp of *Pisifera* variety has no distinct kernel shell [21]. The oil content of palm fruits depends on the thickness of the mesocarp, where *Teneras* have 30% more mesocarp and 30% greater oil content in bunches than *Duras* [22]. Ariffin [23] stated that the differences in average OER values between Malaysia, Indonesia and Thailand could be due to the mesocarp to nut ratio. This is the prominent factor that contributes to attaining high OER value. Thus, oil palm plantations in Malaysia are opting to cultivate oil palm with improved characteristics to achieve high OER.

It was reported that when the cultivation of *Duras* was switched to DxP hybrid, it triggered an increase in oil productivity up to 30%, but then the oil yield became stagnant for more than two decades [24]. On another note, the FFB production capability and OER among the *Tenera*s depend on their genetic [25]. To increase oil yield, a hybrid oil palm seed with unique characteristics was produced by an oil palm research centre known as Applied Agricultural Resources Sdn. Bhd (AAR). The hybrid has features such as lower height, longer economic life span, shorter and lighter fronds, compacted crown, a high number of FFB, and smaller palm size that can facilitate harvesting. They are also trying to produce another hybrid oil palm seed with longer bunch stalk to facilitate harvesting without the requirement of frond pruning below the bunch and to facilitate weevil pollinators to pollinate the entire inflorescence to produce well pollinated FFBs.

In Malaysia, research and development (R&D) in oil palm fruits are not only focusing on hybrids, but they also investigate cloning the fruits for further improvement in oil productivity. Cloning high yield planting material for the industry is expected to create the second wave in oil productivity. The attempt for cloning via tissue culture technique has started since the 1960s through 1970s with a successful result. In a few decades later, a large-scale propagation of oil palm clones was preceded in order to increase oil productivity [24]. According to Soh et al. [26], data obtained from field performance of various sources showed that an improvement of oil yield between 20% and 30% over seedling planting materials was achievable by clonal materials. A pilot commercial test planting for clones reported by Soh et al. [27] also proved that the oil yield of clones exceeded that of DxP controls by 7-34% in FFB, signifying prospective improvement of oil yield can be attained with cloning. However, these clones are reported to be susceptible to defects and abnormalities as well as facing a few issues, such as composition, planting configuration and agro-management practice which need to be addressed.

Another alternative to producing high oil yield planting material is the utilisation of oil palm hybrid fruits between different species [24]. The interspecific hybrid seeds of *Elaeis oleifera* and *Elaeis guineensis* are produced worldwide. These hybrids are tolerant of spear rot, shorter palms and compact with more liquid oil

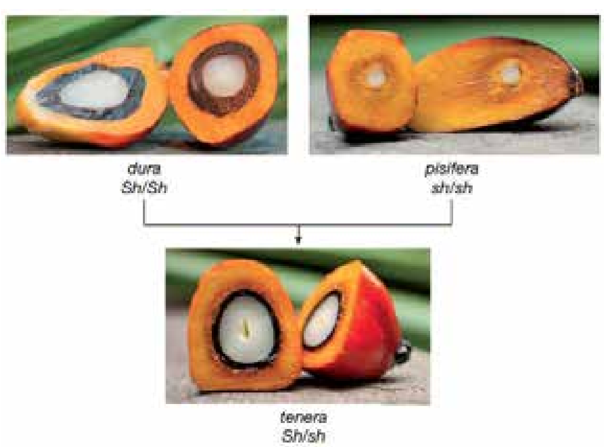


Figure 3 Three generic forms of oil palm fruits; *Dura*, *Pisifera* and *Tenera* (DxP)

compared to the intraspecific hybrid of *Elaeis guineensis Dura* and *Pisifera* [24]. Approximately 22% of the total area under Malaysian oil palm cultivation constitutes old plantings, age 19 years and above, require replanting [28]. Hence, the productivity of oil is expected to increase when these oil palm hybrids and clones fruits are ready to be cultivated in the replanting process as an evolution to current oil palm species at a massive scale.

Processing of loose fruits

In the standard operating procedure, mature FFB is highly related to a large number of loose fruits [29]. A good ripeness standard is suggested to be indicated by one loose fruit per bunch. Most palm oil mills use one loose fruit as the minimum standard, with a harvesting interval of seven to 10 days [30]. Such a measure is more practical as it ensures minimal loose fruits, quickly recovered and not wasted. Uncollected loose fruits have been identified as one of the factors that contribute to oil losses in the Malaysian palm oil industry, as the loose fruits make up approximately 7-8% of FFB weight that contributes to 3-4% of OER [29]. Ariffin [30] also stated that loose fruit consignment might contain as high as 45% oil. Due to its contribution to increasing OER, some mills purchase loose fruits at higher prices than FFBs [31]-[32].

98.9% using vibration and airstream mechanism. Nevertheless, operators are required to wear personal protective equipment as the machine produced a high sound level (above 90 dB). Another machine invention for loose fruits collection has been reported by Shuib et al. [35] using a cyclonic vacuum concept that could reduce fruits bruising. This machine also has the capability to separate loose fruits and debris where the heavier fruits fell to the bottom of the vacuum chamber, while lighter debris such as dried leaves was sucked out from the machine. An average of 1500-2000 kg of clean loose fruits can be collected in a day. The operators can operate the machine efficiently with fast operation and reduce the back-pain problem.

On another note, Janius & Eskandar [35] emphasized that the loose fruits collectors invented must be able to be used continuously in the real field and should adapt to various ground conditions of real plantations. Most of the collectors developed did not consider the plantation terrains, difficulty to pick fruits near palm trunk or frond, and maneuverability of the machine at the plantations [36]. By resolving these issues, the collection of loose fruits can be carried out accordingly and at the same time, reduces oil losses. Figure 4 shows an example of loose fruits at the plantation.

(a) (b)

Figure 4 Example of loose fruits at (a) oil palm plantation, (b) palm oil mill

Normally, loose fruits are collected either by raking or picking by hand. However, it is labour intensive and time-consuming. In addition, when gathered, trash content can be as high as 60% by weight, which eventually affects the calculation of OER. Thus, the application of newly invented machines to enhance the collection of loose fruits at the plantation has been reported. Nadzri & Ahmad [33] developed a prototype of loose fruit collection system using a robotic mechanism as well as roller picker for collection with tyres attached to the prototype for smooth movement on various ground conditions. It uses a wireless controller to control the robot. The study claimed that the use of this prototype had reduced time and fruits damage [33]. However, it was not mentioned whether it could be easily operated by plantation workers to collect loose fruits at the real plantation. An oil palm loose fruits collecting machine has been recently developed by Khalid & Shuib [34] with the capability of separating loose fruits from trash effectively by

Processing of ripe bunches

The initial process of obtaining good quality and high CPO productivity should start from understanding the crop itself. In order to optimise the quality of oil produced, the FFBs should be harvested at optimum maturity. Mandal and Kochu Babu [37] reported that the oil formation is maximum during the last two weeks of bunch maturity. Thus, any premature harvesting would result in underperformance of the palm. This is also supported by Ariffin [30], who stated that a longer ripening period would lead to higher oil content. Fruits on the bunch take 20-22 weeks to ripen. From about the fifteenth week, the mesocarp enlarges, and the cells in the mesocarp start to synthesise storage oil. The amount of oil in ripe FFB ranges between 23% and 27%. Due to the various types of FFB in a consignment, the average oil content maybe about 20-24%. The fruits ripening process is mostly affected by chemicals and climatic changes. Although a ripe bunch indicates maximum oil content, it is not necessarily optimum [30].

Prior to harvesting, the maturity stage should be accurately ascertained and comprehended. There are five different classes of FFB ripeness as established by Malaysian Palm Oil Board, namely ripe, under ripe, overripe, unripe and rotten [38]. The colours vary from black (or green) to orange for ripe fruits with different degrees of black colours depending on light exposure and cultivar [39]. The OER for ripe and unripe fruit differs by about 3.5%. This contributes to a significant difference in the amount of oil extracted at a large scale. The oil content for an unripe bunch is assumed to be 30% lower than that of ripe bunches [40]. Besides, a decrease of 0.13% in OER is observed for every 1% of unripe bunches present [41]. In addition, damaged fruits and overripe bunches tend to result in oil with high free fatty acid (FFA) content and thus, lowering the quality of the oil. In order to obtain maximum recovery with standard quality of CPO, a compulsory minimum 95% FFB ripeness must be met by any oil palm estate before sending the FFB to the mills [42]. Researchers also found that the quality of oil contents in oil palm fruits is related to the moisture contents in the fruits as well as fruit ripeness. When fruits are ripening, the oil content reaches its maximum while the moisture content reaches its minimum [43].

In Malaysia, ripeness grading is normally carried out manually in the palm oil mills. Visual assessment fruits' colour is still considered as the simplest and most direct way of assessing the quality of FFB [44]. Colour provides helpful information in predicting the maturity and examining the freshness of fruits as it is the most significant criterion to identify fruit quality and a good indicator for ripeness [45]. Changes in fruits colour explicitly depend on changes in ripeness. Experienced workers used colour to determine whether the fruits are categorised as under-ripe, ripe, or overripe. However, it is difficult to differentiate between darkish red (*i.e.* overripe), reddish-orange (*i.e.* ripe), and purplish-red (*i.e.* under-ripe) using visual inspection alone. Colour is very subjective in the manual inspection as different graders may fail to evaluate the grading criteria properly. Figure 5 depicts the example of ripe fresh fruit bunch.

To increase the accuracy and quality of FFB grading in palm oil mills, automation grading has been an interest to researchers compared to manual inspection. May and Amaran [45] developed a technique to overcome the subjectivity and inconsistency of the manual grading technique. Colour intensity was used to differentiate fruits' maturity using a computer, CCD camera and MATLAB software using fuzzy logic for decision-making. This method was proven to improve the grading system with 88.74% efficiency. However, instead of using sunlight, the grading evaluation was carried out indoor under controlled lighting, which did not represent the real condition in the palm oil mill.

On the other hand, Harun *et al.* [44] applied a sensor to investigate the frequency characteristics of air coils with various diameters to determine the maturity of FBBs. Although great potential has been reported, the implementation of this device to the real field is still unknown. Another technique called neutron backscattered technique was employed by Mustapha et al. [46] to estimate oil content for ripe, under-ripe and bruised fruits and it was found that higher neutron count and hydrogen indicated more oil content in the fruits. This non-destructive technique can be used as a real-time grading system for oil palm. In conclusion, the automated grading system shows explicit potential to improve the grading system of FFB maturity compared to manual inspection. Identifying the physiological maturity and harvesting of matured FFB will avoid cutting of either under-ripe or overripe fruits [45]. However, handling of automation grading should be performed by skilled workers. Therefore, training must be given to the workers beforehand so that automation grading can be implemented successfully in palm oil plantations, hence improving the quality of oil palm harvested.

Reduction of unstripped bunches

Unstripped bunches (USB) is identified as one of the sources of oil loss (Figure 6). The presence of USB reflects the inefficiency of sterilisation and threshing operation. Besides, it also indicates the level of unripe or under-ripe bunches processed [47]. The presence of USB after sterilisation and threshing is probably due to incomplete hydrolysis of hemicelluloses caused by

Figure 5 Example of ripe fresh fruit bunch

insufficient sterilisation and inefficient heat penetration to the FFB. In contrast, complete hydrolysis of hemicelluloses leads to complete separation of fruits from the stalks and subsequently produces zero USB. A lack of steady-state conditions can also cause the reduction of fruits detachment during stripping due to fluctuating steam load, particularly by the intermittent and manually operated fuel-feed system.

In most conventional mills, triple-peak sterilisation has become standard practice as it is the most effective cooking technique used to reduce the amount of USB [48]. It is executed by purging as much air as possible and blowing down the steriliser for each batch of FFB to almost zero pressure, three times for each cooking cycle. The purpose is to ensure that heat is distributed uniformly to the whole fruits and bunches for good stripping. However, this technique consumes a lot of steam and requires the installation of large capacity boiler for the supply of steam to be adequate and consistent to achieve triple-peak sterilisation, and thus facilitate good stripping [48]. Nevertheless, an improvement in the sterilisation process has been carried out for better oil yield and reduction of oil loss.

Apart from batch sterilisation, continuous sterilisation is one of the steaming methods implemented in several mills in Malaysia (Figure 7). As compared to conventional sterilisation, continuous sterilisation uses saturated steam at atmospheric pressure to heat the FFB with uniform temperature. It is also equipped with a double-roll crusher to distort the close-knit arrangement of spikelets in the bunches [49]. Crushing the fruit bunch into spikelet may facilitate the heat penetration to the outer and inner layer of fruits and ease the detachment process. Although crushing the FFB would result in theoretically high FFA before continuous sterilisation, insignificant deterioration of oil quality from bruising of the mesocarp is observed if the bunches are heated immediately after crushing [50]. Without using multiple peak cycles, the crushed bunches are conveyed and heated at the same time inside the closed sterilisation chamber. This technique is said to be better in terms of power consumption and reduces manpower significantly [51]. In terms of fruits detachment, Sivasothy *et al.* [49] demonstrated that merely 2-3% of bunches had unstripped fruits from continuous sterilisation. They also made a comparative study on the effectiveness of hand peeling of mesocarp from the nuts and found that 24.1% of fruits from batch sterilisation could not be

Figure 6 Unstripped bunches after threshing operation

Figure 7 Continuous steriliser

peeled off versus 2.13% in continuous sterilisation. In addition, this method preserved high moisture and oil content in the mesocarp fibre [49]. Also, sterilisation time and steam pressure required to achieve complete stripping of the fruits from crushed bunches were reported to be lower than that used for normal bunches [11].

Alternatively, a ball-shaped steriliser vessel or spherical steriliser has also been designed for the sterilisation of FFB. A study performed by Kumaradevan et al. [40] described that the spherical chamber, rotating on two horizontally aligned shafts to the chamber's centre, can be rotated 180° to pour out its contents. Steam is supplied in a concentric pipe through each anchoring shaft. Generally, the spherical steriliser is more efficient than conventional steriliser, as the process can be scaled up and transporting carts are not necessary [40]. This is also supported by Chan [52], where spherical steriliser has high efficiency that enables improvement of OER by 1-2% compared to conventional horizontal steriliser. The presence of USB after threshing is below 1.5%, excluding hard bunches [52]. Figure 8 displays the example of the spherical steriliser.

Vertical steriliser, as shown in Figure 9, is another promising technology which has been designed to improve the sterilisation process. The operation has been described by Karmegam Karuppiah *et al.* [53] where the FFBs are placed in a vertical vessel and sterilised at 4 bar steam pressure using multiple peaks cycles similar to horizontal steriliser. This type of steriliser is convenient for space-saving in palm oil mills. Without using steel cages, the vertical steriliser uses a conveyor to transport FFB from the loading ramp to the steriliser, which reduces manual handling. As a result, the occurrence of fruits bruising can be limited and thereby reduces the formation of FFA in crude palm oil [53]. In terms of heat distribution, Purwanto [54] simulated heat transfer inside vertical steriliser using the finite-difference-explicit method. The aim was to predict the required time for the heat to penetrate the sterilised FFB fully. It was found that the predicted time was 105.2 minutes with low steam demand. The occurrence of USB using spherical steriliser was reported to be less than 3% [55].

Figure 8 Spherical steriliser

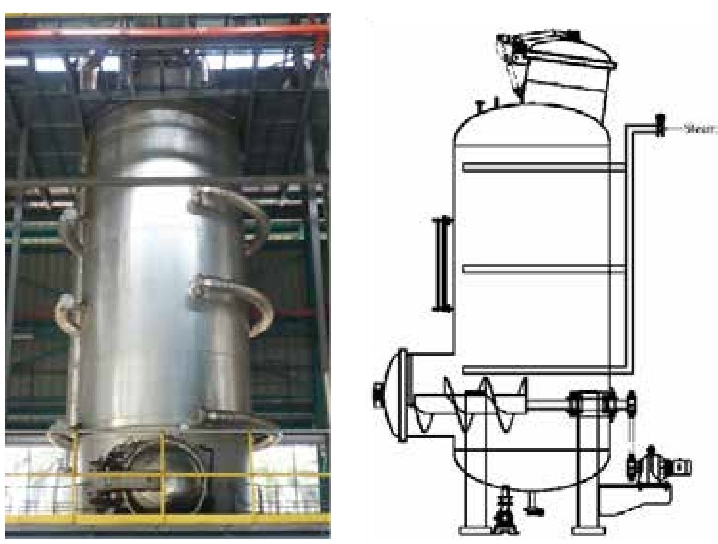


Figure 9 Vertical steriliser

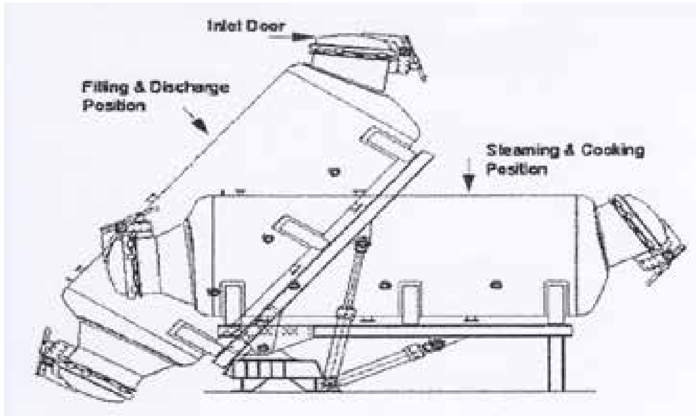


Figure 10 Operation of tilting steriliser [58]

Tilting steriliser is another invention for sterilisation process enhancement. Loh [55] described this steriliser to operate similar to horizontal steriliser using pressurised steam. The difference is that this steriliser is tilted in an inclined position to discharge sterilised FFB under gravity through the bottom outlet into a collection hopper after sterilisation process is ceased [55] (Figure 10). Among the advantages of tilting steriliser, in comparison to conventional steriliser, are faster cycle time (less than 80 minutes), low oil loss, less steam consumption, low heat loss, and less wastewater discharge. In addition, the incident of USB was reported to be less than 1% due to a well-designed steam distribution and venting system to ensure efficient cooking of FFB [55]. Both vertical and tilting sterilisers are reported to be efficient, reduces labour and maintenance costs, as well as easy to operate [56].

Potential methods such as dry heating and microwave heating have also gained interest in current research and development. These methods were developed in order to overcome the use of highly pressurised steam that will generate a great amount of wastewater due to a large amount of water used in the sterilisation process [57]. The great potential has been shown in the use of both techniques in the sterilisation process. Cheng et al. [58] deduced that extending the duration of fruits exposure to microwave give greater effect on the kernel than mesocarp. Prolonged heating will damage the fruits as this technique only worked for the outer layer of the fruits. Strippability of fruits from bunches in microwave sterilisation can be related to microwave dielectric properties and moisture content surrounding the abscission layer of palm oil fruitlets, by means the ability of the bunch to absorb microwave energy [59]. It was revealed that the moisture content in the abscission regions was higher than other regions of the fruitlets, resulted in 80% stripping efficiency. Therefore, microwave radiation is feasible for quick detachment of the fruitlets from the bunch as the abscission layer is heated by absorbing the electric field and loosens the fruits without any damage or bruise.

Microwave sterilisation has been proven to deactivate enzyme, such as lipase effectively, and produce better quality storage oil with lower FFA content [59]. The results are quite similar to a study conducted by Hadi et al. [60] which stated that dry heating exposed the palm fruits to potential burning. This study incorporated the sterilisation process by dry heating together with solvent extraction. Even though the oil yield was high, longer heating time caused the kernel to be overcooked. Fruits underwent dry-heating process tended to have hardened mesocarp making the depericarp operation difficult [60]. Nonetheless, scriptability efficiency was not discussed in the study. Most of the previous work was conducted at laboratory scale using small portions of oil palm bunches. Not many reports on the implementation of dry-heating and microwave sterilisation in actual mills in terms of its efficiency and economic feasibility are available. Therefore, a large-scale microwave sterilisation system for implementation in palm oil mills requires further studies.

The occurrence of oil losses can also be related to the use of non-optimal processing variables, such as sterilisation time and steam pressure [18]. Thus, a high pressure equilibrated sterilisation technique was introduced, which used a pressure of 70 psi and operated for 30 minutes [14]. It was found that this technique has led to zero production of USB regardless of grades of fruits. More water and less oil were measured in the pressed fibre of the sterilised, digested and pressed fruit mesocarp. It was also observed that the mesocarp was softer after sterilisation at 70 psi, compared to that of 40 psi, which eventually increased the OER by at least 2%. However, it should be noted that the temperature used must not be higher than 150°C as it will affect the carotenes content in the oil [14]. All in all, the efficiency of the sterilisation process will determine the success of subsequent processes. Good sterilisation ensures maximum fruit recovery during stripping or threshing, as well as in other operations.

Oil Losses at Waste Stream

Attention should be given to control and manage oil loss at every stage in the whole milling process, particularly at the waste streams, namely steriliser condensate, pressed mesocarp fibre and sludge from clarification process. Inefficient old machines for processing in some mills may result in high oil losses throughout operation [16].

Oil loss in condensate

It was estimated that the oil content in steriliser condensate (Figure 11) was approximately 0.07-0.64% per FFB [22]. According to Oi-Ming et al. [61], some oil-bearing cells in the fruits may be heavily bruised during harvesting and transportation of the FFB to the mill. At 1-hour sterilisation operation with the temperature of 130ºC and pressure of 30 psi, it was found that oil from the bruised fruits will be quickly released to the steam and floated when the steam is condensed. Therefore, the amount of oil loss largely depends on the condition of FFB fed to the steriliser, where less bruised fruits indicate low oil loss. Using high-pressure steam of 70 psi for sterilisation is one of the solutions to deal with this problem. Not only will it facilitate the detachment of fruits from the stalk, it also reduces the production of condensate and reduces oil content in the condensate due to shorter cycle compared to sterilisation using 40 psi pressure. Moreover, processing bruised fruits and overripe bunches in large portion should be avoided in order to reduce the oil content in the condensate. Due to high iron content in oils recovered from steriliser condensate, it was suggested that the recovered oil is used as technical oils rather than mixing it with CPO as the stability of the oil will be reduced [56].

Figure 11 Condensate from steriliser

Oil loss in pressed mesocarp fibre

Screw press technology is mostly used in conventional mills for oil extraction from steam sterilised fruits [62]. In conventional palm oil milling, the screw press is attached together with digester. The oil retained in the pressed mesocarp fibre after extraction is approximately 0.45-0.76% per FFB [22]. According to Oi-Ming et al. [61], absorption or incomplete digestion of fruits from the digestion process caused oil retained in the pressed mesocarp fibre. The oil loss could also be attributed to a mixture of different types of oil palm fruits during processing. For example, when the digestion process involves a mixture of oil palm fruit with a high proportion of *Pisifera* to *Tenera/Dura* ratio, there will be high oil retention in the pressed mesocarp fibre and sludge. This is because the *Pisifera* has a high mesocarp to kernel ratio, which is difficult to press and generates a lot of sludge, hence results in inefficient oil recovery. Another contributing factor could be due to the inefficient shearing effect of the stirrer in the digester, which unable to completely rupture the oil-bearing cell walls to release the oil. The retained oil in the pressed mesocarp fibre cannot be recovered, but the amount of oil loss must be recorded and used as a guide to ascertain the efficiency of pressing or sterilisation of the fruits. The oil loss in pressed mesocarp fibre can be minimised by operating the screw press at the correct pressure. Applying too high pressure will result in high broken nuts [63], which in turn will contaminate the crude oil with kernel oil. If the pressure is too low, the fibre may still contain a certain amount of oil [18]. Amelia et al. [18] stated that the processing variable for digester might influence oil losses that could be due to digesting time and temperature. If time is too short, the separation of fruits from nuts will not be perfect, which leads to high oil losses. Therefore, factors such as proper sterilisation, correct digestion process, and applying appropriate pressure during mesocarp fibre pressing will reduce oil loss. Figure 12 exhibits pressed mesocarp fibre at the screw press.

Oil loss in clarification sludge

After the pressing process, larger particles contained in the extracted mixture of oil must be removed, and this process requires the addition of water to improve separation efficiency. This process is carried out using a vibrating screen. Based on the material balance of palm oil milling process for 100 tons FFB [64], the total crude oil produced after pressing is 46.5% of FFB, with 55% oil, 35% water and 10% solids. After that, the mixture of oil, water, and non-organic solid flows into clarifier or settling tank for oil separation. The underflow sludge from the clarifier is another contributor to oil loss that basically occurs due to poor separation process. The clarification process used for the separation of oil from water and suspended solids is performed in a settling tank. By the effect of gravity, the denser water and debris settle at the bottom of the clarifier leaving clean and light oil on top of the clarifier to be skimmed off later. Generally, 0.32–0.60% oil content per FFB present in the sludge.[25] In order to improve settling efficiency, Chungsiriporn *et al.* [65] recommended that the settling temperature should be within 90°C to 97°C. The high temperature helps to reduce the viscosity of oil and leads to better separation [66]. The use of impeller is also reported to enhance the separation of oil and sludge, thus reducing the oil content in underflow and increasing pure oil obtained.

The issue in the conventional process of clarification is the use of a centrifugal pump to pump in oil from vibrating screen into settling tank. This pump, although cheaper compared to other types of pumps, causes the emulsion to occur and oil entrapped in the cell walls. Another drawback of the conventional clarification process is slow oil particles settling rate due to small settling area for effective separation. Under normal 30% hot water dilution, the standard

Figure 12 Mesocarp fibre after screw press

Figure 13 Sludge obtained from sludge separator

clarifier design enables oil to settle within 4 to 7 hours. As a result, oil is prone to hydrolysis, oxidation and other chemical reactions which will affect the oil quality. Figure 13 depicts sludge obtained from sludge separator. Table 1 shows the estimation of oil losses occurred in palm oil mills, as reported by Ng [71].

Table 1 Estimation of oil losses in palm oil mills

Source	Oil loss (% on FFB)
Fruit trapped in empty fruit bunches (EFB)	0.02
Unstripped bunches (USB)	0.05
Oil absorbed on the surface of EFB	0.45
Condensate from sterilisation	0.10
Nut surface after pressing	0.05
Pressed fibre after pressing	0.55
Sludge from separator	0.45
General oil spillages or washing from tanks	0.10
Total oil losses	1.77

Effect of Oil Loss On Cpo Revenue

Oil loss and OER are critical parameters that can represent the profitability of an oil palm mill. A significant reduction of OER results in profit losses for the company. A gross overview shows a revenue loss of RM 350,000 per month 1% reduction in OER, based on the average market price of CPO at RM 2,500 per ton [10]. Simeh [67] emphasised that the profit margin of a palm oil mill depends primarily on oil and kernel extraction rate. Therefore, the decline of these two factors may adversely affect the financial strength of the mill. As reported by Chang *et al.* [8], the Malaysian palm oil industry has incurred the greatest loss in the year 1999 with an oil loss of 790,000 tonnes or 7.5% of the year's CPO production. This is equivalent to a loss of RM109/tonne of CPO and recorded a loss of 8% of export revenue for the same year, which amounted to RM14.41 billion [21]. Moreover, it has been deduced that for the past 10 years, a total revenue loss of CPO due to the difference in annual OER and the benchmark of 20% OER had reached RM6.9 billion [8].

In addition, oil losses at waste streams that are represented by retained oil or residue oil can also contribute to the reduction of CPO revenue. In 2011, the national oil loss in pressed mesocarp fibre alone was reported to be in the range of 236,375 to 520,025 tonnes CPO which was equivalent to a loss of RM700 million to RM1.5 billion with CPO priced at RM3000 [63]. In conclusion, a large difference in OER and high amount of oil loss could lead to a high loss in CPO revenue as well.

Future Outlook of Malaysian CPO

Recent issues and challenges have stormed the Malaysian government and palm oil industry which include import restriction and high import duty imposed by the major exporters of CPO affecting the export, import and revenue. The volatility of CPO prices is influenced by the world palm oil and soybean market price, as well as the increasing demand for palm oil products. Various actions have been implemented by the government to escalate the CPO production and expand the market by diversifying the export markets, technologies advancement and complying with international standards through MSPO certification.

In addition, Malaysia is among the oil-producing countries with the potential to capture the largest market share for biodiesel [68]. The implementation of B7 and B10 biodiesel locally was successful for the industrial and transport sectors, respectively. The B20 biodiesel program involving blending 20% palm methyl esters (PME) with 80% petroleum diesel will be implemented in the Malaysian transport sector gradually [69]. The application of CPO as feedstock for biodiesel also could sustain the demand and stable the commodity price.

The executive director of the Council of Palm Oil Producing Countries (CPOPC), Tan Sri Yusuf Basiron stated that in an interview with the reporters that the stock of the world vegetable oils may deplete rendering the price outlook for palm oil to increase. The CPO demands for biodiesel application will increase if the blending of diesel with PME increases. In fact, China has become the highest importer of CPO in 2019 and will continue its reputation due to edible and industrial demand [70]. Thus, the outlook of Malaysian CPO seems more promising for the coming year.

Conclusion

The ultimate objectives aimed by the decision-makers in the palm oil industry are to maximise the production of CPO by increasing the OER and minimise the oil loss. National OER has not improved for a few years, which could be affected by several factors. This paper has highlighted the technical factors that may contribute to oil losses in the palm oil production process and the possibility of alleviating those factors to attain high OER. The oil losses are reported to have a significant impact on the CPO revenues, whereby the increase in oil loss will decrease the revenue. In the year 2020, the future outlook for Malaysian CPO is promising. It is expected that the use of CPO as feedstock for biodiesel will sustain the CPO demand and stable the price. Thus, understanding on the factors contributing to the oil losses in palm oil production process should be enhanced so that the new proposed technologies can be implemented immediately in the palm oil mills and eventually create a sustainable palm oil production process.

References

[1] B.S. Jalani, Y. Basiron, A. Darus, K.W. Chan & N.Rajanaidu, "Prospects of elevating national oil palm productivity: A Malaysian perspective", *Oil Palm Industrial Economy Journal*, 2, 2, pp. 1-9, 2002.

[2] Y. Basiron, "Palm oil production through sustainable plantations", *Eur. J. Lipid Sci. Technology,* 109, 4, pp. 289-295, 2007.

[3] MPOB, *Malaysian Oil Palm Statistics,* 2017, 37th Ed. Bangi: MPOB, p. 205, 2018.

[4] Y.N. Lee, "Increase Malaysia Palm Oil Production Efficiency", Master's Thesis, University of Bergen, Norway, 2011.

[5] A. Kushairi, K.L. Soh, I. Azman, H. Elina, O.A. Meilina, M.N.I Zanal Bidin, G. Razmah, S. Shamala, A.P. Ghulam Kadir, "Oil palm economic performance in Malaysia and R&D progress in 2017", *Journal Oil Palm Res*, 30, 2, pp. 163-195, 2018.

[6] MPOB, "*Overview of the Malaysian Oil Palm Industry*", 2017. Retrieved 5 December 2017 from http://bepi.mpob.gov.my/images/overview/Overview_of_Industry_2017.pdf.

[7] The British Standards Institution, "*RSPO and MSPO for Sustainable Palm Oil*", 2018. Retrieved 7 May 2018 from https://www.bsigroup.com/en-MY/RSPO-MSPO-Certification/.

[8] L.C. Chang, A.S. Abdul Rahim & B. Zainon, "An economic perspective of oil extraction rate in the oil palm industry of Malaysia", *Oil Palm Industry Economic Journal*, 3, 1, pp, 25-31, 2003.

[9] MPOB, "Pocketbook Oil Palm Statistics 2017", *Malaysian Palm Oil Board,* 2017.

[10] F. Zulkefli, N. Othman, S. Syahlan, M.R. Zaini & M.A Bakar, "Fresh fruit bunch quality and oil losses in milling processes as factors that affect the extraction rate of palm oil", *International Journal of Agriculture, Forestry and Plantation*, 5, pp. 99-103, 2017.

[11] K. Sivasothy, M.H. Rohaya, B. Yusof, A.R. Zulkiflim & A.N. Ma, "Continuous sterilization of fresh fruit bunches", *MPOB Information Series*, 148, 2002.

[12] K. Simarani, M.A Hassan, S. Abd-Aziz, M. Wakisaka, Y. Shirai, "Effect of palm oil mill sterilization process on the physicochemical characteristics and enzymatic hydrolysis of empty fruit bunch", *Asian Journal of Biotechnology*, 1, pp. 57-66, 2009.

[13] Y.R. Noerhidajat, Z.A. Zurina, S. Syafiie, V. Ramanaidu, U. Rashid, "Effect of high pressurized sterilization on oil palm fruit digestion operation", *International Food Research Journal*, 23(1), pp. 129-134, 2016.

[14] A,A. Ariffin, "High Pressure equilibrated sterilization of fresh fruit bunches (FFB) for zero USB (unstripped fruit bunches) and 5% max. oil to pressed fibre (ODM)" in *XVII International Oil Palm Conference*, Cartagena, Colombia, 2012.

[15] G.K. Ahmad Parveez, A.A. Astimar, M.H. Rohaya, "Palm Oil Milling and Processing Handbook", *Malaysian Palm Oil Board*, 2019.

[16] A. Hassan, N.H. Muhammad, A.R. Zulkifli, M.H. Rohaya, A. Halsiyanti & M. Sabtu, "Improving mill oil extraction rate under the Malaysian National Key Economic Area", *Palm Oil Engineering Bulletin*, 103, pp. 39-47, 2012,

[17] A. Embrandiri, M.H. Ibrahim & R.P. Singh, "Palm oil mill wastes utilization: Sustainability in the Malaysian context", *International Journal Science Res. Pub*., 3, 3, pp. 1-7, 2013.

[18] L. Amelia, D.A. Wahab, Hassan A., "Modelling of oil palm production using the fuzzy expert system", *Expert System Application*, 36, pp. 8735-8749, 2009.

[19] M.H.M. Hazir, A.R.M. Shariff, "Oil palm physical and optical characteristics from two different planting materials", *Res. Journal Appl. Sci. Eng. Technology*, 3, 9, pp. 953-962, 2011.

[20] C.H. Teoh, , "The Palm Oil Industry in Malaysia: From Seed to Frying Pan". 2002. [Online]. Retrieved 30 February, 2018 from http://www.brandeis.edu/investigate/slavery/docs/palm/From-Seed-to-Frying Pan_WWF.pdf.

[21] A. Kuntom & A.A. Ariffin, "Flavors of Palm Oil", *Handbook of Fruit and Vegetable Flavours*, New Jersey: John Wiley & Sons, Inc., 2010.

[22] R.H.V. Corley & P.B. Tinker, *The Oil Palm*. Fifth Edition, New Jersey: Wiley Blackwell, 2016.

[23] A.A., Ariffin "High Pressure equilibrated sterilization of fresh fruit bunches (FFB) for zero USB (unstripped fruit bunches) and 5% max. oil to pressed fibre (ODM)" in *XVII International Oil Palm Conference*, Cartagena, Colombia, 2012.

[24] A. Kushairi, A.H. Tarmizi, I, Zamzuri, M. Ong-Abdullah, R. Samsul Kamal, S.E. Ooi, N. Rajanaidu, "Production, performance and advances in oil palm tissue culture" in *International Seminar on Advances in Oil Palm Tissue Culture*, Yogyakarta, Indonesia, 2010.

[25] W.W. Chee, "The Advancement of Oil Palm Breeding", 2011. Retrieved 6 February, 2018 from http://www.aarsb.com.my/the-advancement-of-oil-palm-breeding.

[26] A.C. Soh, "Super yielding oil palm – Strategic breeding plan" in *Advances in Breeding and Clonal Technologies for Super Yielding Planting Materials National Seminar*, Kuala Lumpur, Malaysia, 2005.

[27] A.C. Soh, G. Wong, C.C. Tan, P.S. Chew, S.P. Chong, Y.W. Ho, C.K. Wong, C.M. Choo, H, Nor Azura & K. Kumar, "Commercial-scale propagation and planting of elite oil palm clones", *Research And Development Towards Realization. Journal Of Oil Palm Research*, 23, pp. 935-952, 2011.

[28] A. Kushairi, A.H. Tarmizi, I. Zamzuri, M. Ong-Abdullah & O. Rohani, "Current status of oil palm tissue culture in Malaysia" in *Proceedings of Clonal and Quantity Representative Material*, MPOB, Bangi, Selangor, Malaysia, 2006.

[29] M.S.M. Kassim, W.I. Wan Ishak, R.A. Rahman Ramli, B.S. Khairunniza, "Oil palm fresh fruit bunches (FFB) growth determination system to support harvesting operation", *Journal Food Agricultural Environment*, 10, 2, pp. 620-625, 2012.

[30] A.A. Ariffin, "Ripeness standard and palm fruit maturity affecting oil extraction rate (OER)" in *The International Conference and Exhibition of Palm Oil*, Jakarta, Indonesia, 2011.

[31] S. Mohamad, "On the Fresh Fruit Bunch Quality, Ripeness Standard and Oil Extraction Rate", 2007. Retrieved 21 July 2019 from http://www.mpob.gov.my.

[32] M.U. Orji & T.I. Mbata, "Effect of extraction methods on the quality and spoilage of Nigerian palm oil", *African Journal Biochem. Res*., 2, 9, pp. 192-196, 2008.

[33] M.M. Nadzri & A. Ahmad, "Roller picker robot (Ropicot 1.0) for loose fruit collection system", *ARPN Journal Eng. Application Sciences*, 11, 4, 2016.

[34] Khalid M R, Shuib A. R., "Performance of oil palm loose fruits separating machine", *Journal of Oil Palm Research*, 29, 3, pp. 358-365, 2017.

[35] Shuib A. R, Khalid M. R, Mohd Bakri M. A, Deraman M. S, Kamarudin N. Development of oil palm loose fruit collecting machine with elevated discharge mechanism", *International Journal of Engineering Research and Technology (IJERT)*, 7, 10, pp. 193-202, 2018.

[35] R.B. Janius& A. Eskandar, "Performance evaluation of a terrain-accommodating oil palm loose fruit collector", *Pertanika Journal Sci. Technology*, 15, 1, pp. 15-23, 2007.

[36] S. Mohamad, "On the Fresh Fruit Bunch Quality, Ripeness Standard and Oil Extraction Rate", 2007. [Online]. Retrieved 21 July 2019 from http://www.mpob.gov.my.

[37] P.K. Mandal & B.M. Kochu., "Bunch analysis of oil palm", *Technical Bulletin*, 8. 2008.

[38] M.J. Junaidah, A.R. Norizzah, O. Zaliha & S. Mohamad, "Optimisation of sterilization process for oil palm fresh fruit bunch at different ripeness", *International Food Research Journal*, 22, 1, pp. 275-282, 2015.

[39] A.O. Ojomo, F.O. Ologunagba & S.A. Alagha "Performance evaluation of a palm fruit bunch stripper", *ARPN Journal Eng. Application Science*, 5, 9, pp. 29-33, 2010.

[40] D. Kumaradevan, K.H. Chuah, L.K. Moey, V, Mohan & W.T. Wan, "Optimising the operational parameters of a spherical sterilizer for the treatment of oil palm fresh fruit bunch", *Material Science Eng*ineering, 88, pp. 12-31, 2015.

[41] I.M. Siregar, "Assessment of ripeness and crop quality control", in *Proceedings of Malaysian Inter Agricultural Oil Palm Conference*, Kuala Lumpur, Malaysia, 1976.

[42] M.J. Junaidah, A.R. Norizzah & O. Zaliha, "Effect of sterilization process on the deterioration of bleachability index (DOBI) of crude palm oil (CPO) extracted from different degree of oil palm ripeness", *International Journal Bioscience, Biochemical & Bioinforma*., 3, 4, pp. 322-327, 2013.

[43] K.Y. You, Z. Abbas & K. Khalid, "Application of microwave moisture sensor for determination of oil palm fruit ripeness", *Meas. Sci. Rev.*, 10, 1, pp. 7-14, 2010.

[44] N.H. Harun, N. Misron, R.M. Sidek, I. Aris, D. Ahmad, H. Wakiwaka & K. Tashir, "Investigations on a novel inductive concept frequency technique for the grading of oil palm fresh fruit bunches", *Sensors,* 13, pp. 2254-266, 2013.

[45] Z. May & M.H. Amaran, "Automated ripeness assessment of oil palm fruit using RGB and fuzzy logic technique", in *Proceedings of the 13th WSEAS International Conference on Mathematical and Computational Methods in Science and Engineering*, Catania, Italy, 2011.

[46] I. Mustapha, M. Samihah, A.R. Md Fakarudin, Y. Roslan, D. Lahasen, M.H. Nor Pa'iza, A. Jaafar & A. Nik Rosli, "Neutron backscattered technique for quantification of oil palm fruit oil content", *Jurnal Sains Nuklear Malaysia,* 25, 1, pp. 25-29, 2013.

[47] Z. Ab Rahman & R.Mamat, "Fully stripped bunches in palm oil mills", *MPOB Information Series*, No. 111, pp. 1511-7871, 2011.

[48] R.J. Hamilton, "Developments in Oils and Fats", US, *Springer Science and Business Media*, 2012.

[49] K. Sivasothy, Y. Basiron, A. Suki, R.M. Taha, T.Y. Hwa & M. Sulong, "Continuous sterilization: The new paradigm for modernizing palm oil milling", *Journal Oil Palm Research*, 18 Special Issue, pp. 144-152, 2006.

[50] K. Sivasothy, "A new approach to plant-wide automation of palm oil mills", in *Proceedings of the 2005 MPOB National Seminar*, MPOB, Bangi, 2005.

[51] C.J. Vincent, R. Shamsudin, A.S. Baharuddin, "Pre-treatment of oil palm fruits: A review", *Journal Food Engineering*, 143, pp. 123-131, 2014.

[52] J. Chan, "3C Spherical FFB Sterilizer 2.0 - A Cost-Efficient Tool in Palm Oil Extraction in the 21st Century", 2015. [Online] Retrieved 4 March 2019 from http://spherical-sterilizer-palm-oil-mill.blogspot.my/.

[53] K. Karmegam, M.H. Hafiz & M.T. Shamsul Bahri, "Hazard and risk analysis of different sterilizer technology in palm oil mills", *Adv. Environ. Biol.*, 8, 15, Special Issue, pp. 85-90, 2014.

[54] H. Purwanto, "Comparison of Vertical and Continuous Sterilizers in Palm Oil Mill", Master's Thesis, Universiti Putra Malaysia, 2012.

[55] T.T. Loh, "Tilting sterilizer", *Palm Oil Engineering Bulletin,* 94, pp. 29-42, 2010.

[56] W.L. Siew, "Palm Oil: Edible Oil Processing", 2011. [Online] Retrieved 22 July 2019 from http://lipidlibrary.aocs.org/OilsFats/content.cfm?ItemNumber=40334.

[57] I. Umudee, M. Chongcheawchamnan, M. Kiatweerasakul, C. Tongurai, "Sterilization of oil palm fresh fruit using microwave technique", *International Journal Chemical Engineering Application*, 4,3, pp. 111-113, 2013.

[58] S.F. Cheng, L. Mohd Nor & C.H Chuah., "Microwave treatment: A clean and dry method for palm oil production", *Ind. Crop. Prod.,* 34, 1, pp. 967-971, 2011.

[59] N. Sukaribin & K. Khalid, "Effectiveness of sterilization of oil palm bunch using microwave technology", *Ind. Crop. Prod.,* 30(2), pp. 179-183, 2009.

[60] N.A. Hadi, M.H. Ng, Y.M. Choo & A.N. Ma, "Dry-heating of palm fruits: Effect on selected parameters", *Am. Journal Engineering Application Sci*., 5, 2, pp.128-131, 2012.

[61] L. Oi-Ming, T. Chin-Ping & C.A. Casimir. "Palm Oil: Production, Processing, Characterization and Uses", Urbana: AOCS Press, 2012.

[62] N.A. Nik Norulaini, A. Anees, M.N. Fatehah, S.B. Adel Ashur, I.S. Md Zaidul & A.K. Mohd Omar, "Sterilization and extraction of palm oil from screw pressed palm fruit fibre using supercritical carbon dioxide", *Sep. Purifi. Technology*, 60, pp. 272–277, 2008.

[63] S. Vijaya, N.R. Menon, S. Helmi & Y.M. Choo, "The development of a residual oil recovery system to increase the revenue of a palm oil mill", *Journal Oil Palm Research,* 25, 1, pp. 116-122, 2013,

[64] N.R. Menon, "Datasheet-Material balance for processing 100 t fresh fruit bunches", *Palm Oil Engineering Bulletin*, 121, pp.55, 2016.

[65] J. Chungsiriporn, S. Prasertsan & C. Bunyakan, "Study towards cleaner production by palm oil mills: Modelling of oil separation for horizontal settling tank", *Asian Journal Energy Environment*, 6, 1, pp.17-37, 2005.

[66] K. Nurulhuda, "Separation Technique of Crude Palm Oil at Clarification Area via Optimum Parameters", Master's Thesis. Universiti Malaysia Pahang, Malaysia, 2009.

[67] M.A. Simeh, "Factors are affecting fluctuations in net returns from the processing of oil palm fruit bunches", *Oil Palm Industry Economic Journal*, 2, 1, pp, 28-33, 2002.

[68] S. Mohammadi, F.M. Arshad & A. Ibragimov, "Future prospects and policy implications for biodiesel production in Malaysia: A system dynamics approach", *Institutions and Economies,* 8, 4, pp. 42-57, 2016.

[69] Bernama, "Biodiesel B20 programme set to enhance palm oil demand, price stability", *The Edge Markets*, 2020. [Online] Retrieved from https://www.theedgemarkets.com/article/biodiesel-b20-programme-set-enhance-palm-oil-demand-price-stability

[70] Bernama, "Palm oil welcomes 2020 with a bang!", *The Malay Mail*, 2020. Retrieved from https://www.malaymail.com/news/money/2020/01/05/palm-oil-welcomes-2020-with-a-bang/1824835