OCL 2021, 28, 23

https://doi.org/10.1051/ocl/2021011

OCL Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

REVIEW

OPEN ACCESS

Food quality assurance of crude palm oil: a review on toxic ester feedstock

Ainul Farhani Ahmad Nizam and Mohd Sabri Mahmud*

Department of Chemical Engineering, College of Engineering, Universiti Malaysia Pahang, Tun Razak Highway, Gambang, 26300 Kuantan, Pahang, Malaysia

Received 16 April 2020 – Accepted 8 March 2021

Abstract – Palm oil, the commodity produced mainly in Indonesia and Malaysia, is widely used for deep-frying of fast food and food derivatives. European and American markets of palm oil are affected by the concern of the toxicity potential from monochloropropanediol esters (MCPDE) and glycidyl ester (GE) that are undesirably produced from monoacylglycerol (MAG), diacylglycerol (DAG) and chlorine in refineries. Improvement of oil palm plantation, fruit harvest and oil extraction process in palm oil mills is necessary before the refinery process so that hydrolysis reactions that produce MAG and DAG and chlorine contamination can be minimized in crude palm oil (CPO). This review focuses on the quality control currently employed in the mills especially in managing free fatty acid (FFA) formation as the indicator of the hydrolysis reactions along with other quality control parameters and the reduction of chlorine content.

Keywords: monochloropropanediol / glycidyl esters / crude palm oil / food quality / food contaminant

Résumé – Assurance qualité alimentaire de l'huile de palme brute : un examen des matières premières à base d'esters toxiques. L'huile de palme, produite principalement en Indonésie et en Malaisie, est largement utilisée pour la friture des aliments de restauration rapide et de leurs dérivés. Les marchés européens et américains de l'huile de palme s'inquiètent de la potentielle toxicité des esters de monochloropropanediol (MCPDE) et de glycidyle (GE) qui sont produits de manière indésirable à partir de monoacylglycérol (MAG), de diacylglycérol (DAG) et de chlore dans les raffineries. L'amélioration des plantations de palmiers à huile, de la récolte des fruits et du processus d'extraction de l'huile dans les usines d'huile de palme est nécessaire avant le processus de raffinage afin que les réactions d'hydrolyse qui produisent du MAG et du DAG et la contamination au chlore puissent être minimisées dans l'huile de palme brute (CPO). Cette étude se concentre sur le contrôle qualité actuellement employé dans les usines, en particulier pour gérer la formation d'acides gras libres (AGL) comme indicateur des réactions d'hydrolyse ainsi que d'autres paramètres du contrôle qualité et la réduction de la teneur en chlore.

Mots clés : monochloropropanediol / esters glycidyliques / huile de palme brute / qualité des aliments / contaminant alimentaire

1 Introduction

Palm oil industry is one of the sectors that contribute to the economy of many tropical countries. Two species of palm trees (Genus: *Elaeis*) are known: *Elaeis guineensis* and *Elaeis oleifera*. *E. guineensis* was mainly found in West Africa and was cultivated in Malaysia by British in 1870's as an ornamental plant before being developed for commercial purposes in the earlier 19th century (Keong, 2017; Supriyono, 2018; MPOC, 2021). Meanwhile, *E. oleifera* is native to South and Central America. Indonesia, as the largest palm oil producer, supplied 57% of world palm oil production in 2019, followed by Malaysia (27%), Thailand (4%), Colombia (2%), Nigeria (1%) and others (8%) (Mundi, 2020). Factors that promote successful palm oil industries particularly in Indonesia and Malaysia include plantation areas, suitable climate and good management of research and development (Basiron and Weng, 2004).

Palm oil is produced, traded and consumed at large scale over the world, and supersedes production of other vegetable oils such as soybean oil, rapeseed oil and sunflower oil especially in food industries (Matthäus, 2007). According to Sambanthamurthi *et al.* (2000), its content of unsaturated and

*Correspondence: mohdsabri@ump.edu.my

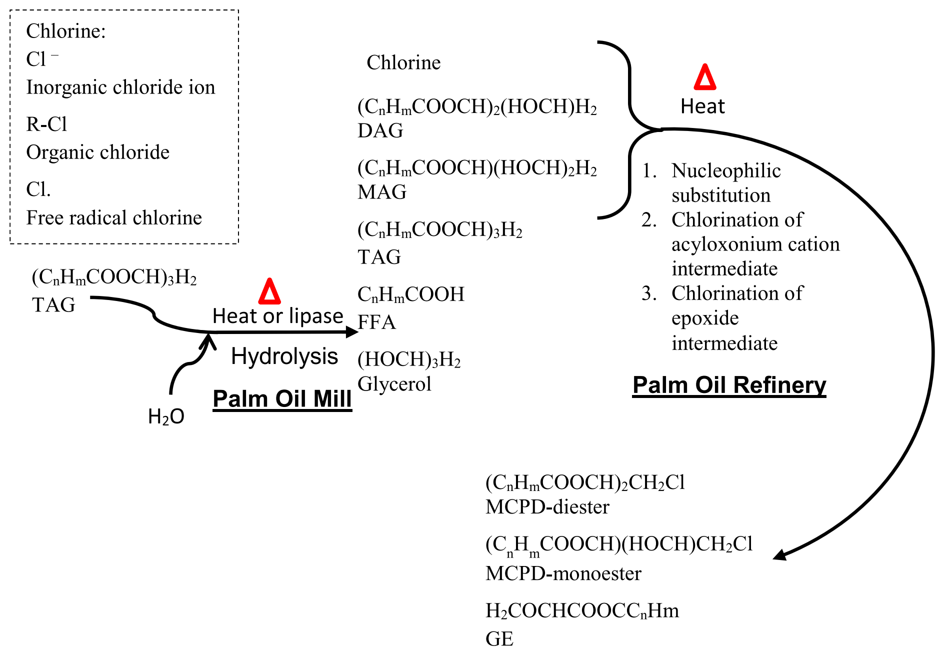

Fig. 1. Schematic diagram of the route of MCPDE and GE formation (Gao *et al.*, 2019).

saturated fatty acids is well balanced with 39% oleic acid (monounsaturated), 11% linoleic acid (polyunsaturated), 44% palmitic acid, 5% stearic acid and 1% myristic acid, respectively, although not enabling to fulfil the recommended daily intake alone. Eighty percent of the market is for frying fast foods due to its stability for repeated cooking compared to most vegetable oils. The rest is as derivatives in food industries where strict regulations are imposed (Mba *et al.*, 2015). Long time ago, palmitic acid content was perceived to have cardiovascular disease effect on body lipid profile prevalent to heart disease ("Joint WHO-FAO expert consultation on diet, nutrition, and the prevention of chronic diseases", 2003). Further studies however found that palm oil has similar profile effect to monounsaturated oleic acid (Odia *et al.*, 2015) and the study helped regain customer's trust and market. Meanwhile, palm oil was found to contain toxic fatty acid monochloropropanediol esters (MCPDE) and fatty acid glycidyl esters (GE) (Bakhiya *et al.*, 2011; Pudel *et al.*, 2011; Craft *et al.*, 2012; Ramli *et al.*, 2015) although no evidence supports the claim (MPOB, 2014). The demand of many Western countries was influenced again by this concern.

General quality assurance of palm oil production to follow the standard food regulations begins at upstream processes. Food and Agriculture Organization (FAO) and World Health Organization (WHO) in codex committee on fats and oils, have standardized many key components (Nations and WHO, 2017). In particular, free fatty acid (FFA) from virgin oil or crude palm oil (CPO) for food purposes should not exceed 10 mg KOH/oil of acid value (approximately 5 wt%). FFA existence in the oil indicates that the oil hydrolysis reaction has occurred in the palm fruit in the presence of endogenous and microbial lipase or sterilizing steam, and by-products like diacylglycerol (DAG) and monoacylglycerol (MAG) are simultaneously formed. They are the raw materials for MCPDE and GE syntheses in the presence of chlorine in refinery *via* 3 synthesis routes as summarized in Figure 1. Chlorine term used in most of MCPDE and GE papers generally refers to free radical chlorine and all kind of chlorine-contained chemicals, either organic or inorganic substances. To date, no limitation of chlorine content in CPO is imposed by the Codex committee in spite of chlorine mainly coming from CPO. Fertilizers (Afandi *et al.*, 2016), pesticides (Muhamad *et al.*, 2010), soil minerals and treated raw water are the potential sources of chlorine.

Many papers on palm oil have been discussing on the production in perspective of economic sustainability (Lim *et al.*, 2015), processing, characterization and utilization in food industries (Mba *et al.*, 2015). This review discusses findings from various studies and actions taken by industries and relevant authorities in implementing initiatives for improving CPO quality in mills for safe food use, particularly on the reduction of DAG, MAG and chlorine as the feedstock for MCPDE and GE formation. Not many reports were unfortunately published in high impact journals even though they are peer-reviewed and most of the publications in English are from Malaysia. As the impact of palm oil to lipid supply in many food industries is significant, this review perhaps deserve such a high-ranking publication.

2 Fruit harvest and milling process

Ripe palm fruit is characterized by a reddish orange colour and a bunch of matured palm fruits usually weighs around 10 to 40 kg. Each fruit contains a nut that is made up of kernel (endosperm) enclosed by the hard, woody shell (endocarp). This nut is surrounded by fibrous, oily pulp (mesocarp) and is covered by thin-layered skin (exocarp) as shown in Figure 2.

Two weeks after anthesis (WAA), the fruit usually starts to develop and differentiate before the oil accumulates in the mesocarp between 16 WAA and 21 WAA (Oo *et al.*, 1985). According to the researchers, the growth of the palm fruits can

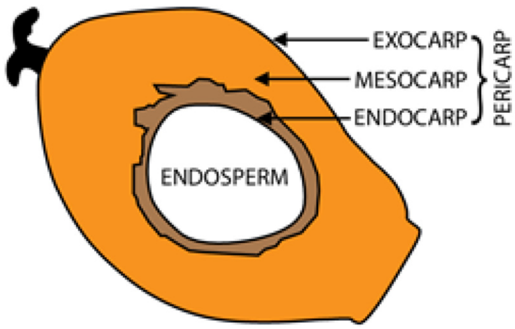

Fig. 2. Main components of palm fruit (Sheil *et al.*, 2009).

be classified into three stages, from the oil deposition until the fully oil occupied mesocarp. Upon the final stage, the fruit matures and the bright yellow mesocarp results from the high content of carotene in the oil (Rangkuti *et al.*, 2018). The three stages of palm fruit growth are summarized in Table 1.

Fresh fruit bunch (FFBs) harvesting process is performed manually by the field workers during regular field visits using sickles attached to pole ends, and oil palm trees and ground are cleaned. The FFBs are then transported to mills for extraction within no more than 24 h to avoid oil loss due to the oil hydrolysis reaction.

Generally, palm oil mills involve five basic unit operations: FFB sterilization, FFB stripping, digestion, oil extraction and oil clarification. FFBs are initially pre-treated in a high-temperature sterilization chamber to deactivate the lipolytic enzymes and loosen fruits (Subramaniam *et al.*, 2010). Both temperature and residence time are closely controlled; the FFBs are steamed at 40 psig and 140°C for 70 to 90 minutes according to Sivasothy *et al.* (2005). The use of high temperature causes the cell wall to rupture and subsequently increase the oil yield (Kasmin *et al.*, 2016). However, over-sterilization may cause other reactions such as oxidation and poor bleachability of the final product which affects its quality (Junaidah *et al.*, 2015).

The sterilized FFBs are then sent to a stripper, which is usually a rotary drum thresher, to separate oil palm fruitlets from stalks and bunches. The separated empty fruit bunches (EFBs) are sent back to plantations as fertilizer, or to boiler as feedstock to generate heat for the factory (Subramaniam *et al.*, 2010), but the latter are equipped with particulate matter traps due to the concern of environmental pollution (Hawari *et al.*, 2018). Meanwhile, the fruitlets are transferred to a digester to separate mesocarp from nuts by rotating beater arms at high temperature between 80 to 90 °C (Subramaniam *et al.*, 2010; Hosseini and Wahid, 2015). This process helps reducing the oil viscosity, destroys the exocarp, and completes the disruption of the oil cells from the sterilization process (Poku, 2002).

The digested mash is subsequently pressed by using a screw press to extract CPO. In this stage, as the pressure increases, more CPO will be squeezed out from the digested mash. Optimum pressing conditions are critical since the kernel will crack if too high pressure is applied, *i.e.* higher than 50 bar, and consequently lead to the contamination as the crude palm kernel oil (CPKO) may squirt from the broken kernels into the CPO (Obibuzor *et al.*, 2012).

The liquid extract is now a mixture of oil, water and vegetable impurities such as cell debris and fibrous materials. Clarification following the pressing process is essential to remove suspended solids from CPO. A vibrating screen is usually used in between, to filter the extract, leaving behind debris. To enhance the process, the CPO is further clarified by gravity in a settling tank followed by a centrifugation step. The decanted CPO is then transferred to a vacuum dryer for moisture removal before it is stored in appropriate containers for export or sent off to the refinery. Table 2 summarizes the purposes of each unit operation in palm oil mills.

The performance of the extraction process, the oil extraction rate (OER), is determined from the mass ratio of final CPO product to fresh fruit bunch, FFBs, as shown in equation (1).

$$\mathrm{OER} = \frac{\text{Mass of extracted oil}}{\text{Mass of a fresh fruit bunch (FFBs)}}. \qquad (1)$$

Some oil usually is lost in the milling process. Zulkefli *et al.* (2017) found that the highest oil loss was in the pressed fibre and in the oily-wet nut. Figure 3 illustrates three-year percentage means of oil losses from wet nuts, sterilizer condensate, final effluent, wastewater, empty bunch and press fibre. However, oil losses due to the quality of FFBs delivered to their mill was not reported and was believed to be higher than all of these data (Zulkefli *et al.*, 2017).

The CPO is refined, deodorized and bleached at refinery. The CPKO or endosperm oil is extracted as well. By having different properties and characteristics, both are used for different purposes where CPO is more suitable for food applications and CPKO for non-food applications such as cosmetics and machinery (Obibuzor *et al.*, 2012).

3 Issue with CPO quality

CPO is a complex mixture of chemicals, 95–99% of triacylglycerol (TAG), DAG, MAG, and FFA. The rest (1–5%), comprises carotenoids, tocopherols, tocotrienols, sterols, phosphatides, aliphatic alcohols and other non-acylglycerol components as shown in Figure 4 (Kumar and Krishna, 2014). Carotenoids, tocopherols and tocotrienols are important in stabilizing the CPO (Nagendran *et al.*, 2000).

CPO normally contains 500 to 4000 ppm of carotenoids. 37% and 50% of them are α- and β-carotene, respectively, which are acceptably high as a vitamin A source (Nagendran *et al.*, 2000): 15 times that of carrots and 300 times that of tomatoes, and as antioxidant and anti-carcinogenic agents, and against cardiovascular diseases (Odia *et al.*, 2015; Santos *et al.*, 2015). Due to light colour preference of the final product, the carotenoid content is reduced during the refinery process. Other two beneficial components are tocopherols and tocotrienols, which provide nutritional properties as vitamin E and similarly act as antioxidant. The presence of the tocopherols and tocotrienols also gives CPO the ability to withstand at high temperature, and thus make it suitable to be used as cooking oil (Okolo and Adejumo, 2014). However, during the refinery process, some of these components are also lost leaving the remaining 69% in palm oil, 76% in palm stearin and 72% in palm olein (Sambanthamurthi *et al.*, 2000).

Table 1. Growth of palm fruits (Oo *et al.*, 1985).

Stage	Parts of individual palm fruit				Estimated week after anthesis (WAA)
	Endosperm	Endocarp	Mesocarp	Exocarp	
First stage	– Starts of oil deposition – Firm	– Fully formed – Easily sliced – Cream-colour	–	– Greenish-yellow colour	12–13
Second stage	– Complete deposition oil	– Hard – Deep brown colour	– Starts of oil deposition – Greenish-yellow colour – Non-oily	– Deep red at outer tip – Orange towards the stalk	16–17
Third stage	–	–	– Bright yellow colour – Filled with oil	– Bright waxy reddish orange	20–21

Table 2. Basic unit operations in palm oil mills.

Unit operation	Purposes	References
FFB sterilization	– To deactivate lipolytic enzyme activities. – To soften the fruit pulp. – To ease the cracking process by heating and partial dehydration of the nuts. – To coagulate the protein in the oil-bearing cells: prevents formation of colloidal complexes and facilitates oil clarification. – To hydrolyze the mucilaginous materials: facilitates oil clarification.	(Kasmin *et al.*, 2016; Owolarafe *et al.*, 2008; Sivasothy *et al.*, 2005)
FFB stripping	– To separate mesocarp fibre and nut.	(Ebongue *et al.*, 2006)
Digestion	– To destroy exocarp. – To digest palm mesocarp into homogeneous mash. – To enhance the oil cell breakdown process. – To reduce the oil viscosity.	(Hosseini and Wahid, 2015; Owolarafe *et al.*, 2008; Poku, 2002; Syahro *et al.*, 2015)
Oil extraction	– To extract oil by pressing process.	(Subramaniam *et al.*, 2010)
Oil clarification	– To yield the pure oil. – To remove water and non-oily solid.	(Subramaniam *et al.*, 2010)

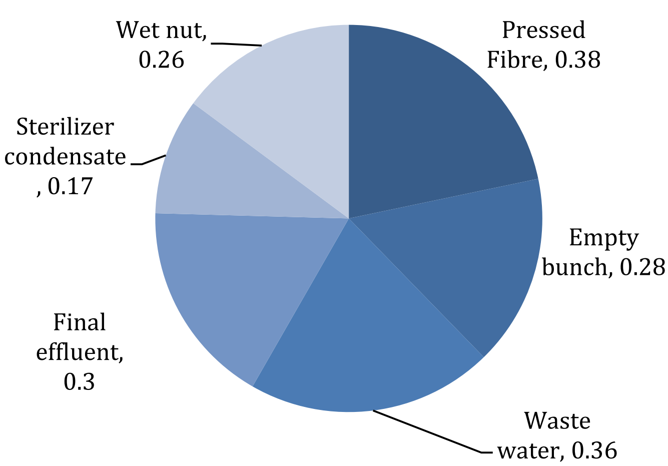

Fig. 3. Percentage of total oil loss in different samples of waste (Zulkefli *et al.*, 2017).

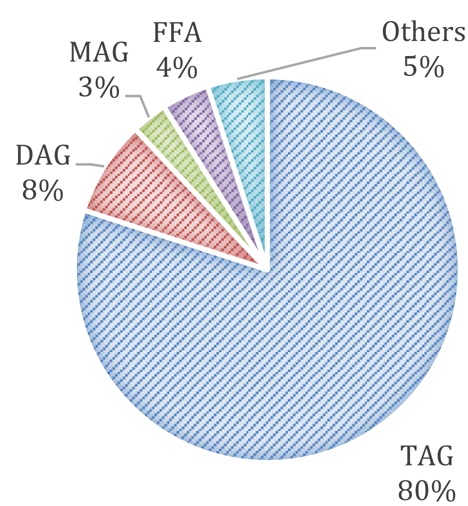

Fig. 4. Composition of CPO (Kumar and Krishna, 2014; Bahadi *et al.*, 2016; Japir *et al.*, 2017).

Physically, CPO has a semi-solid nature at room temperature and may be fractionated into two major fractions based on the acyglycerol crystallization properties (Kellens *et al.*, 2007). At the operation temperature, some of the acylglycerols will solidify and separate from the remaining liquid portion forming two different fractions. The solid fraction with high melting point between 48–50 °C is called palm stearin while the liquid faction with low melting point between 18–20 °C is known as palm olein (Jacobsberg and Ho, 1976).

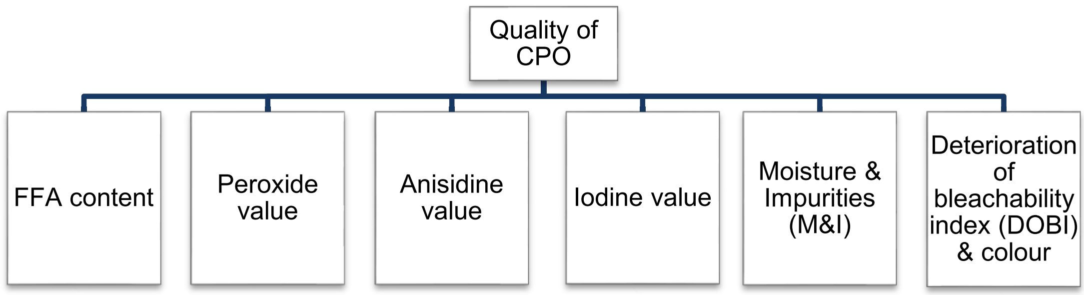

Fig. 5. Parameters for assessing the quality of CPO.

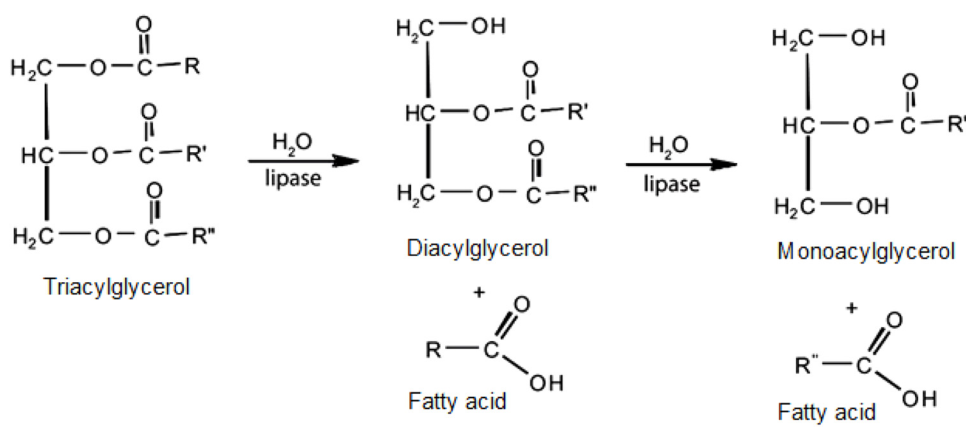

Fig. 6. Steps in the hydrolysis reaction of lipase catalysed TAG.

Both palm stearin and palm olein are commonly found in daily food products such as shortenings and cooking oils, respectively (Kadandale *et al.*, 2019).

CPO is an important raw material for food industry, oleo chemicals and biodiesel that will determine its required quality. The quality is highly dependent on the mill practices, storage and handling of CPO. Figure 5 shows the common parameters used in assessing the CPO quality.

3.1 Free fatty acid

Existence of FFA indicates the formation of MAG and DAG, the reactants for undesired MCPDE and GE formation in refineries, through any of three consecutive hydrolysis reactions of acylglycerols as shown in Figure 6. Hydrolysis speed of DAG and MAG was about 30 times higher than that of TAG hydrolysis in the presence of pancreatic lipase (Mattson and Beck, 1955) indicating that the latter is the limiting step. FFA presence will generate rancidity, and deteriorates palm oil for food consumption (Sambanthamurthi *et al.*, 2000). It is usually assessed and termed as acid value in grading and determining the commercial pricing of CPO (Cadena *et al.*, 2013). FFA should be maintained as low as possible in order to prolong the lifespan of the oil. FFA content is usually around 3–4% in CPO (Kumar and Krishna, 2014). The acceptable limit of FFA content for food application is 5% (Bahadi *et al.*, 2016), and CPO with more than 5% FFA is suitable for other applications such as in the manufacture of biodiesel (Hayyan *et al.*, 2013). Other components in CPO that can generate rancidity and deteriorates of the oil are trace metals, moisture and non-acylglycerol impurities (Nagendran *et al.*, 2000).

FFA content is basically determined by using titration method where sodium hydroxide or potassium hydroxide and phenolphthalein are used as standard solution and indicator respectively (Bahadi *et al.*, 2016; Japir *et al.*, 2017; Ramli *et al.*, 2017; Tan *et al.*, 2017). FFA content may increase due to the enzymatic activities where the presence of endogenous and microbial lipases in the CPO induces the formation of FFA by hydrolysis reaction of the TAG. As a result, more FFA, DAG and MAG will be produced and eventually increases the FFA content of the CPO (Japir *et al.*, 2017). FFA will reduce the cooking oil production in refineries while DAG and MAG are the key feedstock in forming MCPDE and GE in the presence of chlorine. Determination of FFA is important not just due to the loss of oil product but also decreasing the food safety (Gao *et al.*, 2019). Previous studies had found that the lipase activities are highly related to the ripeness level, fruit bruising and post-harvest storage.

Lower FFA level was found in palm oil fruits at 20 WAA compared to 21 WAA, which was attributed to different ripeness (Oo *et al.*, 1985; Sambanthamurthi *et al.*, 1991). It was reported in another study conducted by Tagoe *et al.* (2012) that high level of FFA was found in the palm oil extracted from the over-ripe fruit. This is in agreement with the research done by Morcillo *et al.* (2013) where the increase of FFA was observed when the harvest day was delayed. Detachment due to chopping or over-ripeness and harvested FFBs left for many days will also increase FFA (MPOB, 2015; Teng *et al.*, 2015).

Table 3. Analysis of endogenous lipase activity.

Type	Method of assaying lipase	Substrate	Temperature	pH	Reference
in vitro	Powder obtained from maceration of mesocarp tissue with liquid nitrogen	Glycerol [^{14}C] trioleate	20–45 °C	–	(Henderson and Osborne, 1991)
	Oleic acid released from emulsion	Glycerol [^{14}C] trioleate	Maximum at 18°C	–	(Sambanthamurthi *et al.*, 1995)
	Chemical extraction	Olive oil	Optimum temperature: 45°C Active at 20–50 °C	Optimum pH: 9–10 Not active below 7.0 and above 11.5	(Ebongue *et al.*, 2006)
	Cold induction assay	–	Maximum at 5°C	–	(Sambanthamurthi *et al.*, 1991)
in vivo	Powder obtained from maceration of mesocarp tissue with liquid nitrogen	Glycerol [^{14}C] trioleate	20–45 °C	–	(Henderson and Osborne, 1991)
	Cold induction assay	–	Maximum at 5°C No FFA detected at room temperature or higher (45°C)	–	(Cadena *et al.*, 2013)

Besides, the over-ripe fruit is more susceptible to the bruising and microbial contamination due to the softening of the mesocarp.

Fruit bruising upon harvesting, transportation and moving from the lorry to the hopper promotes the lipase activity and consequently forms FFA (Krisdiarto and Sutiarso, 2016). Approximately 2.88% of the fruitlets in a freshly harvested bunch are bruised and subsequently FFA increases to 30.74% after crushing (Sivasothy and Halim, 2000). Hadi *et al.* (2009) reported that the bruise category has significant effect towards the development of FFA. The minor bruise and unbruised fruit showed no significant difference in the amount of FFA produced while high FFA was produced in both cases of moderate and major bruise. These results are supported by Ali *et al.* (2014) who found a significant difference of FFA in both major and minor bruised fruits after two-hour storage. For a bruised palm fruit, it is possible for FFA content to be as high as 8% to 10% in 40 minutes, while for the unbruised fruit the FFA content may increase only 0.2% in 4 days (Norris, 1979; Ekwenye, 2006).

The formation of FFA increases proportionally with the time hence, the length of storage of the FFBs prior to sterilization process also contributes to the high level of FFA content (Ali *et al.*, 2014). Based on the research done by Kumaradevan *et al.* (2015), the FFA content had not attained the allowed limit of 5% of FFA when the FFBs were stored longer than 72 h after harvest. Meanwhile, it was reported in another study that all the FFBs did not meet the standard required, except for the fresh harvested bunches (Basyuni *et al.*, 2017). A study was done by Hadi *et al.* (2009) to investigate the effect of time interval between stripping and oil extraction towards the formation of FFA. The delay period of 4 to 12 h however did not portray a significant effect in the FFA formation. According to Berger (2006), it is possible to produce CPO with FFA level below than 2.5% by quick harvest to reduce the over-ripe fruitlets. Besides that, the effect of bruise during harvesting is minimized by immediate sterilization using cages to reduce delay time (Berger, 2006).

3.1.1 Lipase activity

Endogenous lipase activities were assayed and studied under several conditions as summarized in Table 3. The activity is genotype-dependent (Sambanthamurthi *et al.*, 2000; Cadena *et al.*, 2013), *E. guineensis* showing higher lipase activity than *E. oleifera*. Previous study showed around 52.7%, 32.9% and < 0.6% FFA were recorded for *E. guineensis*, the hybrid of E. *guineensis* × *E. oleifera*, and *E. oleifera* respectively (Cadena *et al.*, 2013). According to Sambanthamurthi *et al.* (1991), maximum lipase activity in palm fruit was observed at 18°C for in vitro assay and at 5 °C for in vivo assay, respectively. This statement was contended by who reported that the lipase in the palm fruit (in vivo) is sensitive to chilling inactivation at 8 °C. The lipase activity was found to continuously decrease after cooling in the refrigerator. The study was later explained by Sambanthamurthi *et al.* (1995) that the reduction of lipase activity was due to the remarkable increase of FFA in the palm oil. Further study by Cadena *et al.* (2013) agreed that the lipase activity was strongly activated at low temperature of 5 °C for in vivo assay.

Optimum pH of palm lipase activity located in the oil body fraction can be obtained at 7.5 (Sambanthamurthi *et al.*, 2000). Based on the study conducted by Ebongue *et al.* (2006), the activity was not detected below pH 7.0 and above pH 11.5 of palm oil. While lipase activity is deactivated at acidic and strongly basic conditions, it is stated that lipase enzyme is only stable in a hydrophobic environment and will lose its activities in polar environment (Sambanthamurthi *et al.*, 2000).

High possibilities of lipase activity are originated from bacteria and fungi (exogenous lipase). Under suitable growth conditions including carbon and nitrogen sources, temperature, pH and moisture content, the microbes undergo fermentation process and release lipase as one of the products (Muthumari *et al.*, 2016). Factors that favour the multiplication of the microorganisms include contamination of water or soil in the plantation, improper storage of FFBs and delayed processing time (Tagoe *et al.*, 2012). Besides, the over-ripe palm fruit is more susceptible to high lipase activity since the fruit is easily bruised and further contaminated by the microbes. The activity of exogenous lipase was studied by Tombs and Stubbs (1982) and higher FFA content was found at the bruised edge of the fruits compared to middle part. The researchers explained that contamination occurred as the microbes started to penetrate *via* the bruise. Tagoe *et al.* (2012) in his study stated that various species of microorganisms were identified on the palm fruits but most of them would be eliminated throughout the oil extraction process.

Other than enzymatic lipolysis, the reaction of hydrolysis in palm oil may also be caused by the autocatalysis due to the presence of water in the fruit, the second needed liquid phase. In order for autocatalytic hydrolysis to proceed, the water must be present in significant amount and the reaction rate will be depending on the temperature, moisture content and initial FFA concentration (Sambanthamurthi *et al.*, 2000). It was reported that the moisture of palm fruits decreased as the post-harvest storage time increased which could probably explained due to autocatalysis reaction, and also enzymatic hydrolysis (Tagoe *et al.*, 2012).This type of hydrolysis reaction really occurs in the sterilization where plenty of water in the form of steam is used to kill microbes and fungi (Junaidah *et al.*, 2015). There is high possibility for the microbial contamination and autocatalytic hydrolysis to occur at moisture content above 0.2% (Albert and Astride, 2013).

3.2 Other quality assesment

Quality of CPO is also evaluated through other parameters such as peroxide value (PV), anisidine value (AV), iodine value (IV), moisture and impurities (M&I), deterioration of bleachability index (DOBI) and colour. Some of them are indirectly related to above discussed FFA, MAG and DAG formation.

PV is the parameter used to estimate the oil spoilage especially in cooking oils. PV, which is expressed as mill-equivalent of peroxide per 1000 g of the material, is a determination of the oxidized products from the lipid peroxidation process where the unsaturated fatty acids, regardless of FFA or acylglycerols, undergo a chain reaction mechanism at favourable conditions such as the presence of oxygen, high temperature or moisture contents and produce peroxides. In the analysis, the oil will be dissolved in solution of acetic acid and chloroform, and left in saturated potassium iodide for further reaction. The free iodine is then titrated with sodium thiosulfate solution (Ekwenye, 2006; Ngassapaa *et al.*, 2012; Tan *et al.*, 2017; Wahab *et al.*, 2017). Ngassapaa *et al.* (2012) who studied the stability of Tanzania traditionally processed oils and their blends, found that vegetable oils such as palm oil, sesame oil and sunflower oil showed poor stability upon heating at high temperature through the high PV. According to Merwe *et al.* (2003), PV however may not be reliable indicator for the degree of oxidation of palm oil. Long-term storage of the oil gave a trend of decreasing PV, which can lead to a false conclusion (Augustin *et al.*, 2015; Merwe *et al.*, 2003). This can be explained due to the increase of FFA (Paradiso *et al.*, 2010) and conversion of peroxides into the secondary oxidation products (Ariffin, 2001). These findings can be supported by Faridah *et al.* (2015) who studied palm oil quality used for frying fish. The researchers had repeatedly used the palm oil to fry for nine times at 180°C for 15 minutes. It was found that the PV had increased until its maximum on third frying and decreased afterwards. On the other hand, the extraction methods and storage practices could affect the oxidation of the CPO through the presence of metals (Akusu *et al.*, 2000; Wahab *et al.*, 2017). Besides of contamination by metal wear of the equipment, the natural level of metals in CPO was also reported in the range of 0.5 to 1.0 ppm for iron and 0.01 to 0.18 ppm for copper (Chong and Gapor, 1983).

Due to the unstable transitory products, the peroxides further oxidize to form aldehydes and ketones that are responsible for the rancid smell and test of the oil (Ariffin, 2001; Albert and Astride, 2013). These secondary oxidized products are measured as AV based on the absorbance of solution of oil and a solvent at 350 nm (Xu *et al.*, 2014). Based on the research done by Yoshida *et al.* (1992), AV was significantly affected by the presence of FFA. The researchers had studied the AV of the oils and found that the FFA with shorter carboxylic chain had faster oxidation rate. According to Xu *et al.* (2014) who investigated on oxidative stability of edible oils under continuous frying conditions, palm oil showed a moderated change in AV as compared to peanut oil and camellia oil. Metal, temperature, light and oxygen, may also induce the oxidation reaction besides polyunsaturated fatty acids in the oil (Xu *et al.*, 2014). Instead, the oxidation products can be measured as total oxidation value (TOTOX) which includes both primary and secondary oxidation products. While a study conducted by Chew *et al.* (2018) includes the TOTOX value, others studies on MCPDE and GE have presented the PV and AV separately (Aniołowska and Kita, 2015; Wong *et al.*, 2017).

IV is the number of grams of iodine consumed by 100 g of fats. The parameter is used to determine the unsaturated fatty acids or C=C double bonds in the oil by reacting with iodine compound where high IV indicates high unsaturated-fatty acid content in the oil. It is usually analysed by using Wijs method and further titrated with sodium thiosulfate (Ngassapaa *et al.*, 2012; Bahadi *et al.*, 2016; Japir *et al.*, 2017; Ramli *et al.*, 2017). However, this analysis is not related to the elimination of MCPDE and GE as their formation is not affected by presence of double-bond carbon in the aliphatic chain of FFA (Tarmizi *et al.*, 2019).

M&I is another important criterion in grading the CPO quality which has a critical limit at 0.25% based on the standard by Malaysian Palm Oil Board (MPOB) (Berger, 2006; Bahadi *et al.*, 2016). The parameter is analysed by measuring the oil sample weights before and after drying in the oven. The difference in weight will be recorded after constant weight of the dried sample is achieved (Tagoe *et al.*, 2012; Ramli *et al.*, 2017). Water is known as a catalyst for many chemical degradation reactions especially hydrolysis reactions thus excessive moisture content will be harmful to the oil and fat products. High M&I reading will probably increase the process loss as the water will be converted to water vapour and removed from the refinery plant. According to Tagoe *et al.* (2012) who studied on factors influencing the CPO quality at the mills, M&I is one of the sources that favour contamination of microbes towards the CPO. According to the researchers, moisture content is positively correlated with water activity (a_w) whereby the requirement of a_w for growth of bacteria and

Table 4. Parameters used to identify the CPO quality.

Parameter	Purpose	Correlation with good CPO quality	Allowable limit	References
FFA content	Determination of the FFA content. Yield will be reduced when FFA content is high.	Low	< 5.0%	(Ariffin, 2001; Halim and Ngan, 2001; Nations and WHO, 2017)
PV	Determination of the oxidized products from the lipid peroxidation process.	Low	< 2.0 meq/kg	(Ariffin, 2001; Halim and Ngan, 2001; Malaysian Standard, 2007)
AV	Determination of the secondary oxidized products from the lipid peroxidation process.	Low	< 5.0	(Ariffin, 2001; Malaysian Standard, 2007)
IV	Determination of the unsaturated fatty acids or C=C double bonds.	Low	50.1–54.9	(Ekwenye, 2006; Malaysian Standard, 2007; Ramli *et al.*, 2017)
M&I	Determination of the moisture and impurities.	Low	< 0.25%	(Ariffin, 2001; Bahadi *et al.*, 2016; Halim and Ngan, 2001)
DOBI & colour	Determination of the numerical ratio of the UV absorbance of carotene to the UV absorbance of oxidative products.	High	> 2.3	(Ariffin, 2001; Halim and Ngan, 2001; Malaysian Standard, 2007)
Chlorine	Determination of chlorine content. Chlorine will be involved in MCPDE and GE formation.	Low	< 2 ppm	(Kadir, 2019)

fungi are 0.9 and 0.7, respectively. Tagoe *et al.* (2012) had further stated that the presence of M&I in CPO might be caused by the methods of processing. This is supported by Akusu *et al.* (2000) who studied on effect of extraction methods on the stability of CPO whereby the CPO extracted by applying digestion prior to extraction gave higher M&I content compared to that of without digestion. According to Basyuni *et al.* (2017) who investigated the effects of FFB storage on the physicochemical properties of palm oil, freshly harvested bunches indicated the lowest M&I and increased above the standard requirement after 7 days of storage. Other than damaged outer layer, the accumulation of both dirt and mould could be seen on the surface of the FFBs (Basyuni *et al.*, 2017).

Another parameter used to identify the CPO quality is by a numerical ratio of the UV absorbance of carotene (446 nm) to the UV absorbance of oxidative products (269 nm) or so-called DOBI (Kasmin *et al.*, 2016; Tan *et al.*, 2017; Wahab *et al.*, 2017). Although the carotene is highly beneficial for human health, it has to be removed due to the susceptibility to some chemical reactions at high temperatures and light yellowish colour preference of consumers (Ariffin, 2001). The bleaching process will remove organic compounds such as carotenoids, xanthophylles, chlorophyll and their degradation products and impurities, trace metals and high molecular oxidative components from the oil thus improving the colour and taste (Okolo and Adejumo, 2014). According to Jusoh *et al.* (2013), DOBI was highly related to the temperature and time in which over-sterilization will cause high oxidation risk and poor DOBI of the CPO. Residence time in the sterilizer however showed more significant effect as compared to temperature (Junaidah *et al.*, 2013). DOBI and carotene content can also be affected by the length of storage time. Based on the research done by Basyuni *et al.* (2017), after 28 days of harvesting, the oil extracted showed a decreasing trend of DOBI and carotene content. This can be supported by a study on the effect of ripeness level of the FFBs on the DOBI where DOBI value was observed to decrease as the FFBs ripen (Rangkuti *et al.*, 2018). It was further explained due to higher carotene content in the over-ripe fruits compared to ripe and under-ripe fruits. DOBI value indicates the freshness of the fruit similar to AV.

Chlorine in CPO comes from several sources in the upstream process of palm oil production. Besides chloride fertilizer use in plantation (Afandi *et al.*, 2016) the content of the soil also contributes chloride content in oil palm tree and fruit (Chung, 2018). A lot of raw water is used in the extraction process and in many palm oil mills it is treated by using chlorine gas and hypochlorites of sodium or potassium (Menon, 2017). Chlorinated water will be in contact with oil fiber at 100–150 °C and hydrophilic organochlorides may be converted into lipophilic forms during sterilization in the oil pam fruits (Craft *et al.*, 2012). Unfortunately, current processes in many mills do not specifically mitigate chlorine as same as FFA and other contaminants, and thus current improvement progresses is required to satisfy European Safety Authority (EFSA), and European and American markets (Chung, 2018).

Overall, CPO quality is highly determined by the quality of its FFBs received from the plantation. According to research done by Halim and Ngan (2001), two different mills A and B were supplied with 70% and 77% ripe FFBs respectively. Despite of having different processing temperatures, CPO extracted from mill B showed a better oil quality than CPO from mill A by having lower FFA and PV, and higher DOBI and carotene value. Table 4 summarizes the correlation between parameters used and quality. Apart from FFA content (acid value), AV, M&I and chlorine are currently the relevant parameters to control feedstock for MCDPE and GE formation in CPO.

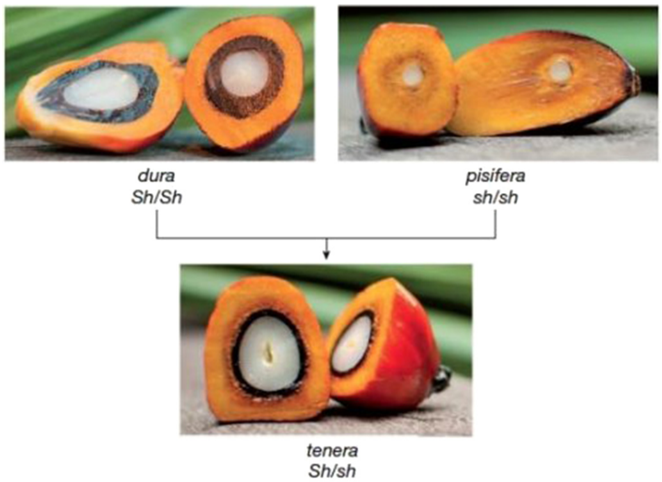

Fig. 7. Different types of oil palm fruits (de Almeida Rios *et al.*, 2018).

4 Current Quality Control

As an important resource for human food industries, palm oil quality is controlled by government and palm oil private sectors by implementing systematic assurance systems that follow international standards such as Hazard Analysis and Critical Control Points (HACCP), ISO 9001 and Good Manufacturing Practices (GMP) (MPOB, 2007; Nazir *et al.*, 2012). Codex international food standard was introduced by the FAO and WHO to provide guidelines, codes and practices in order to protect health of the community and to ensure the fair trade practices (Nations and WHO, 2017). Indonesian Sustainable Palm Oil (ISPO), Malaysian Sustainable Palm Oil (MSPO) and Roundtable Sustainable Palm Oil (RSPO) certifications are currently code of practice employed in most of palm oils in not only production of palm oil but also community and supply chain (Efeca, 2016; Rival *et al.*, 2016).

Quality coordination division assures the oil product complies with the standards and regulations. Meanwhile, the plant manager is responsible to initiate and perform follow-up of the corrective action regarding quality issue. Overall, it is crucial to ensure that the oil produced conform to quality requirement particularly FFA and chlorine content controls.

4.1 Plantation stage

To obtain high quality palm oil product, the process is strictly supervised since the plantation stage. The very first step is to maintain the quality of seedlings by performing cross-pollination of selected parent palms. Generally, there are three different forms of palm fruits namely *dura*, *pisifera* and *tenera* as shown in Figure 7. Each one is differentiated by the physical appearance of mesocarp, endocarp and kernel. Table 5 compares the different characteristics among the three types of palm fruits. Although *pisifera* is shell-less and has the highest mesocarp to fruit ratio, there is low oil content in the pulp. This is because of the *pisifera* does not develop beyond the stage of anthesis (Sambanthamurthi *et al.*, 2009).

In the research of oil productivity in oil palm germplasm type *tenera* by Krualee *et al.* (2013), there are positive correlations between oil production with the production of bunches, bunch weight, fruit to bunch ratio and pulp (mesocarp) to fruit ratio. Another study conducted by de Almeida Rios *et al.* (2018) showed similar results for the germplasm type *dura*. Meanwhile, in term of stability towards the bacterial and fungal deterioration, *tenera* is more stable compared to *dura* (Ekwenye, 2006).

During nursery, the plants are grown in polyethylene bags until 10 to 12 months under close supervision before being field-planted (Muhammad *et al.*, 2010). Two objectives of nursery stage: to ensure the plants are getting sufficient nutrients and protection from the pests. In the plantation field, the spacing between each palm trees is crucial as it may contribute to Basal Stem Rot (BSR) disease, a disease that causes a destruction of basal tissue of the plant and affect palm oil production (Azahar *et al.*, 2011).

Chemical treatment and fertilizers are important to ensure the health of the oil palm tree. Chlorine in the fruit is mostly from pesticides and herbicides such as Diuron (Muhamad *et al.*, 2010), 2,4-D (Kuntom *et al.*, 2007), Aldrin, Endrin, δ-BHC, 4-DDT, Methoxychlor and Endosulfan (Kuntom *et al.*, 2007; Sharip *et al.*, 2017). Reducing their use decreased the cost while the same yield of oil palm fruits remained for 2 years (Darras *et al.*, 2019).

4.2 Harvesting stage

Raw material quality in palm oil processing depends on the ripeness standard of the fruits and feed passing to the digester. The ripeness of palm fruits is particularly related with the FFA content whereby as the fruits ripe, higher FFA will be produced (Oo *et al.*, 1985; Sambanthamurthi *et al.*, 1991; Tagoe *et al.*, 2012; Morcillo *et al.*, 2013). Meanwhile, minimizing dirt on the feed (FFBs) will reduce the probability of the metal wear in the upcoming processes and thus avoid the contamination by iron. Harvesting is thoroughly done by the plantation workers to ensure the appropriate ripeness level and minimal fruit bruising. Minimizing the bruising is one of the proposed improvements of the process of fruit picking and delivery (Menon, 2017) as was directly outlined in standard operating procedures (MPOB, 2015). This procedure is indirectly emphasized in sustainability standards such as Malaysian Sustainable Palm Oil (MSPO) and Roundtable Sustainable Palm Oil (RSPO) (Lim *et al.*, 2015). It is a critical process as the ripeness level and fruit bruising may affect the final product quality through FFA content, DOBI value and colour. The workers are usually guided, well trained and knowledgeable regarding the ripeness standard as regulations are enforced to ensure ripe FFBs are harvested (Hassan and Mohammad, 2005; MPOB, 2007). Natural indicators commonly used to determine the appropriate time to harvest are colour appearance of fruits and number of loose fruits detached (Kassim *et al.*, 2011). It is the roles of field managers to ensure the ripeness of FFBs and manage appropriate harvesting intervals so that only right bunches are picked. The FFBs are then transported to mills for extraction within not more than 24 h to avoid oil loss due to the hydrolysis reaction. Depending on the ripeness level of the oil palm fruits, the oil content is

Table 5. Fruit form characteristics of *dura*, *tenera* and *pisifera* (Sambanthamurthi *et al.*, 2009).

Fruit form characteristic	*Dura*	*Tenera*	*Pisifera**
Shell thickness (mm)	2–8	0.5–4	Shell-less
Fibre ring	Absent	Present	Absent
Mesocarp to fruit ratio (%)	35–55	60–96	95
Kernel to fruit ratio (%)	7–20	3–15	
Oil to bunch (%)	16	26	

*Female sterile where bunches seldom develop to maturity.

approximately 15–25% of its total weight (Sambanthamurthi *et al.*, 2009; Sheil *et al.*, 2009). Although detached fruits are considered as the indicator to the maturity of the FFBs, those fruits especially the bruised ones are usually not taken due to high FFA content (Hadi *et al.*, 2009).

Several studies have introduced other methods but they seemed not practical and tedious. A microwave-based sensor was used to determine the stage of maturity of FFBs based on its moisture and oil content (Abbas *et al.*, 2005; Khalid and Abbas, 1992) but the method was only applicable for the lab-scale works. Similarly, the RGB colour camera was studied to capture an image of the harvested FFBs where the intensity value of red (R), green (G) and blue (B) will differentiate the FFBs into black, hard, ripe, over-ripe, empty and rotten (Ishak *et al.*, 2000; Alfatni *et al.*, 2008). The application faced some limitations in real plantation as the experiment was conducted under controlled environment in the lab (Ishak *et al.*, 2000). Razali *et al.* (2009) and Ishak and Hudzari (2010) had developed a model that determines the FFB maturity by taking into considerations both FFB colour and moisture content. A maturity table was developed by them to manage and display the location of FFBs and the maturity stage. According to the researchers, application of this method to large-scale plantation requires an automated system data collection as data needs to be consistently recorded; time interval between harvesting and sterilizing is reduced as low as possible in order to minimize the lipase activity.

4.3 Milling stage

In palm oil mill processing, there are generally three important things to be considered: to minimize the degradation of oil quality, to keep the product losses at the lowest possible level and to maintain the production cost at the lowest possible level (Eng and Tat, 1985). These can be achieved systematically by having the control on the quality of the raw materials and of manufacturing.

As above said, three inducing factors of FFA formation in palm oil mill process are heat, moisture and catalyst. There are two unit operations involving the heating process: sterilizer and digester. The heating temperature and time are inevitably crucial for both unit operations as the FFA will increase alongside with those variables (Berger, 2010; Junaidah *et al.*, 2015). During the sterilization, heat may not completely penetrate due to various sizes of FFBs and crammed arrangement in the chambers. However, sterilizing the FFBs at longer time or higher temperature will additionally cause slow non-catalytic hydrolysis reaction of oil since moisture is introduced throughout the process (Lau *et al.*, 2006). Besides, the oil is also susceptible to the oxidation reactions and over-sterilization may lead to poor bleachability of the final product (Junaidah *et al.*, 2015). MCPDE and GE contents are not high in CPO but if they are, this sterilization section will be suspected first, because here ionic chlorine (chloride) starts the contact with FFA, DAG and MAG at high temperature (Menon, 2017).

Control of manufacturing quality in palm oil mill can be divided into four categories: process control, process inspection, inspection and test, and machine maintenance (Eng and Tat, 1985; MPOB, 2007).

- *Process control*: Good quality palm oil product and minimal production losses determine the effectiveness of process control. These require knowledge, skills and intensive trainings on how to run machines properly.
- *Process inspection*: The conformity of the processing conditions and product quality will be regularly checked according to the standards. If the product quality is below standard, the overall process needs to be revised by the supervisor.
- *Inspection and test*: The inspection and test division will observe the efficacy of the ongoing process by doing the sampling, testing, and comparing with the standard specifications. Sample testing of palm oil quality should meet the food safety requirements, and these includes the FFA content, PV, AV, IV, M&I, DOBI and colour.
- *Machine maintenance*: Machine maintenance should be performed regularly to avoid the production loss, product contamination and hazardous situation.

Besides the formation of MAG and DAG indicated by the FFA content, chlorine is also the key reactant in the formation of MCPD and GE at refineries. Limitation of chlorine content, either aqueous or organic, has been imposed by Malaysia Government through a circular to all palm oil industries in Malaysia (Kadir, 2019). Chlorine in CPO is removed by second water washing using treated raw water in Malaysian palm oil mills (Yassin, 2018) and following the patent numbered EP 2 716 746 A1 (Yamamoto and Haneishi, 2014). Other possible methods of dechlorination include electrolysis and chemical derivatization with dechlorinating reagents as reported by other patent for waste cooking oil (唐应彪 *et al.*, 2019) and dechlorination of aqueous chlorine by using an adsorbent (Spaparin *et al.*, 2017).

4.4 Storage management

The final oil product requires proper handling to avoid increase of FFA at the storage tank and formation of radical polyunsaturated fat due to autoxidation and photosensitized oxidation with oxygen from air and rusted material (Almeida *et al.*, 2019). Based on the recommended practices of storage and transport of edible oils and fats by MPOB, the suitable material of storage tank for palm oil is either aluminium or 316 stainless steel (Berger, 2010). The cleanliness of the storage tank is assured prior to the oil transfer to maintain the oil quality (MPOB, 2007).

5 Conclusion

As conclusion, the formation of toxic ester during the refinery is highly associated with the quality of CPO from the upstream process. FFA, the main parameter for quality verification indirectly becomes an indicator for the presence of MAG and DAG. Other feedstocks' assessments include AV, M&I and chlorine content. Since chlorine is concerned for being a potential feedstock for MCPDE and GE, the sources should be further investigated and regulated. Current practices in controlling the feedstocks' formation during the upstream process are matter of fruit handling, CPO mill processing and method of storing the final product.

Acknowledgement. The authors would like to express gratitude to Universiti Malaysia Pahang on the research grant number RDU1803159 and PGRS1903123, and to Public Service Department for the study scholarship.

References

Abbas Z, You Kok Y, Shaari AH, Khalid K, Hassan J, Saion E. 2005. Complex permittivity and moisture measurements of oil palm fruits using an open-ended coaxial sensor. *Sensors J IEEE* 5(6): 1281–1287.

Afandi AM, Zulkifli H, Khalid H, Hasnol O, Zuhaili HAZAN, Zuraidah T. 2016. Oil palm fertilizer recommandation for Sabah soils. *Oil Palm Bull* 72: 1–24.

Akusu MO, Achinewhu SC, Mitchell J. 2000. Quality attributes and storage stability of locally and mechanically extracted crude palm oils in selected communities in Rivers and Bayelsa States, Nigeria. *Plant Foods Human Nutr* 55: 119–126.

Albert M-ME, Astride EM. 2013. Some quality parameters of crude palm oil from major markets of Douala, Cameroon. *Afr J Food Sci* 7(12): 473–478. https://doi.org/10.5897/ajfs2013.1014.

Alfatni MSM, Shariff ARM, Shafri HZM, Saaed OMB, Eshanta OM. 2008. Oil palm fruit bunch grading system using red, green and blue digital number. *J Appl Sci* 8(8): 1444–1452.

Ali FS, Shamsuddin R, Yunus R. 2014. Effect of chopping oil palm fruit spikelets on the free fatty acid content release rate and its mechanical properties. *Int J Res Eng Technol* 3(1): 511–516.

Almeida DTD, Viana TV, Costa MM, Silva CDS, Feitosa S. 2019. Effects of different storage conditions on the oxidative stability of crude and refined palm oil, olein and stearin (Elaeis guineensis). *Food Sci Technol* 39(suppl 1): 211–217. https://doi.org/10.1590/fst.43317.

Aniołowska M, Kita A. 2015. The effect of type of oil and degree of degradation on glycidyl esters content during the frying of french fries. *J Am Oil Chem Soc* 92: 1621–1631. https://doi.org/10.1007/s11746-015-2715-3.

Ariffin AA. 2001. The effect of CPO quality parameters (FFA, M&I, IV, PV, AV, DOBI and colour) on the refinery production efficiency. In: *Paper presented at the 2000 National Seminar on Palm Oil Milling, Refining Technology, Quality and Environment*, Pahang, Malaysia.

Augustin G, Anne MN, Armand AB, Moses MC. 2015. Some physicochemical characteristics and storage stability of crude palm oils (Elaeis guineensis Jacq). *Am J Food Sci Technol* 3(4): 97–102. https://doi.org/10.12691/ajfst-3-4-1.

Azahar TM, Mustapha JC, Mazliham S, Boursier P. 2011. Temporal analysis of Basal Stem Rot disease in oil palm plantations: An analysis on peat soil. *Int J Eng Technol* 11(3): 96–101.

Bahadi MA, Japir A-W., Salih N, Salimon J. 2016. Free Fatty Acids Separation from Malaysian High Free Fatty Acid Crude Palm Oil Using Molecular Distillation. *Malay J Anal Sci* 20(5): 1042–1051. https://doi.org/10.17576/mjas-2016-2005-08.

Bakhiya N, Abraham K, Gurtler R, Appel KE, Lampen A. 2011. Toxicological assessment of 3-chloropropane-1, 2-diol and glycidol fatty acid esters in food. *Mol Nutr Food Res* 55(4): 509–521. https://doi.org/10.1002/mnfr.201000550.

Basiron Y, Weng CK. 2004. The oil palm and its sustainability. *J Oil Palm Res* 16(1): 1–10.

Basyuni M, Amri N, Putri LAP, Syahputra I, Arifiyanto D. 2017. Characteristics of fresh fruit bunch yield and the physicochemical qualities of palm oil during storage in North Sumatra, Indonesia. *Ind J Chem* 17(2): 182–190. https://doi.org/10.22146/ijc.24910.

Berger KG. 2006. Understanding oils and fats. *Global Oil Fat Bus Mag* 3(4).

Berger KG. 2010. Recommended practices for storage and transport of edible oils and fats. Retrieved from http://www.palmoilworld.org/PDFs/Storage.pdf.

Cadena T, Prada F, Perea A, Romero HM. 2013. Lipase activity, mesocarp oil content, and iodine value in oil palm fruits of Elaeis guineensis, Elaeis oleifera, and the interspecific hybrid O × G (E. oleifera × E. guineensis). *J Sci Food Agric* 93(3): 674–680. https://doi.org/10.1002/jsfa.5940.

Chew S-C, Chin-Ping T, Lai O-M, Nyam K-L. 2018. Changes in 3-MCPD esters, glycidyl esters, bioactive compounds and oxidation indexes during kenaf seed oil refining. *Food Sci Biotechnol* 27(3): 905–914. https://doi.org/10.1007/s10068-017-0295-8.

Chong CL, Gapor MT. 1983. Effects of moisture and trace metals on oil quality. Palm Oil Research Institute Malaysia.

Chung AYK. 2018. Crude palm oil de-chlorination. *Palm Oil Eng Bull* 128(2018): 51–57.

Craft BD, Nagy K, Seefelder W, Dubois M, Destaillats F. 2012. Glycidyl esters in refined palm (Elaeis guineensis) oil and related fractions. Part II: practical recommendations for effective mitigation. *Food Chem* 132(1): 73–79. https://doi.org/10.1016/j.foodchem.2011.10.034.

Darras KFA, Corre MD, Formaglio G, *et al.* 2019. Reducing Fertilizer and Avoiding Herbicides in Oil Palm Plantations – Ecological and Economic Valuations. *Front Forests Global Change* 2. https://doi.org/10.3389/ffgc.2019.00065.

de Almeida Rios S, Vieira da Cunha RN, Lopes R, *et al.* 2018. Correlation and Path analysis for yield components in Dura oil palm germplasm. *Ind Crops Prod* 112: 724–733. https://doi.org/10.1016/j.indcrop.2017.12.054.

Ebongue GFN, Dhouib R, Carrière F, Zollo PHA, Arondel V. 2006. Assaying lipase activity from oil palm fruit (Elaeis guineensis Jacq.) mesocarp. *Plant Phys Biochem* 44(10): 611–617. https://doi.org/10.1016/j.plaphy.2006.09.006.

Efeca. 2016. Comparison of the ISPO, MSPO and RSPO.
Ekwenye UN. 2006. Chemical characteristics of palm oil biodeterioration. *Biokemistri* 18(2): 141–149.
Eng TG, Tat MM. 1985. Quality control in fruit processing. *J Am Oil Chem Soc* 62(2): 274–282.
Faridah DN, Lioe HN, Palupi NS, Kahfi J. 2015. Detection of FFA and PV values using FTIR for quality measurement in palm oil frying activities. *J Oil Palm Res* 27(2): 156–167.
Gao B, Li Y, Huang G, Yu L. 2019. Fatty Acid Esters of 3-Monochloropropanediol: A Review. *Ann Rev Food Sci Technol* 10 (1): 259–284. https://doi.org/10.1146/annurev-food-032818-121245.
Hadi S, Ahmad D, Akande FB. 2009. Determination of the bruise indexes of oil palm fruits. *J Food Eng* 95(2): 322–326. https://doi.org/10.1016/j.jfoodeng.2009.05.010.
Halim RM, Ngan MA. 2001. Effect of temperature on the quality of fresh crude palm oil at different stages of processing. *Oil Palm Bull* 43: 31–37.
Hassan A, Mohammad JA. 2005. Regulations on Quality of FFB. *Oil Palm Bull* 50: 31–38.
Hawari Y, Halim RM, Aziz AA. 2018. Review on technologies advancement for particulate emision reduction in palm oil mill. *Palm Oil Eng Bull* (129): 42–53.
Hayyan A, Mjalli FS, Hashim MA, AlNashef IM. 2013. Conversion of free fatty acids in low grade crude palm oil to methyl esters for biodiesel production using chromosulfuric acid. *Bulg Chem Commun* 45(3): 394–399.
Henderson J, Osborne DJ. 1991. Lipase activity in ripening and mature fruit of the oil palm – stability in vivo and in vitro. *Phytochemistry* 30(4): 1073–1078. https://doi.org/10.1016/s0031-9422(00)95175-6.
Hosseini SE, Wahid MA. 2015. Pollutant in palm oil production process. *J Air Waste Manag Assoc* 65(7): 773–781. https://doi.org/10.1080/10962247.2013.873092.
Ishak WIW, Bardaie MZ, Hamid AMA. 2000. Optical properties for mechanical harvesting of oil palm FFB. *J Oil Palm Res* 12: 38–45.
Ishak WIW, Hudzari MR. 2010. Image based modeling for oil palm fruit maturity prediction. *Int J Food Agric Environ* 8(2): 469–476.
Jacobsberg B, Ho OC. 1976. Studies in palm oil crystallization. *J Am Oil Chem Soc* 53(10): 609–617.
Japir AA-W, Salimon J, Derawi D, Bahadi M, Al-Shuja'a S, Yusop MR. 2017. Physicochemical characteristics of high free fatty acid crude palm oil. *OCL* 24(5): D506. https://doi.org/10.1051/ocl/2017033.
Joint WHO-FAO expert consultation on diet, nutrition, and the prevention of chronic diseases. 2003. http://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf;jsessionid=3CA350E9D87905AC4005DEB9457C0010?sequence=1 (Retrieved from 15/4/2020).
Junaidah MJ, Norizzah AR, Zaliha O. 2013. Effect of sterilization process on deterioration of bleachability index (DOBI) of crude palm oil (CPO) extracted from different degree of oil palm ripeness. *Int J Biosci Biochem Bioinform* 3(4): 322–327. https://doi.org/10.7763/IJBBB2013.V3.223.
Junaidah MJ, Norizzah AR, Zaliha O, Mohamad S. 2015. Optimisation of sterilisation process for oil palm fresh fruit bunch at different ripeness. *Int Food Res J* 22(1): 275–282.
Jusoh JM, Rashid NA, Omar Z. 2013. Effect of sterilization process on deterioration of bleachability index (DOBI) of crude palm oil (CPO) extracted from different degree of oil palm ripeness. *Int J Biosci Biochem Bioinform* 3(4): 322–327.
Kadandale S, Marten R, Smith R. 2019. The palm oil industry and noncommunicable diseases. *Bull World Health Organ* 97(2): 118–128. https://doi.org/10.2471/BLT.18.220434.
Kadir APG. 2019. Penguatkuasaan Tambahan Syarat Lesen yang Dikenakan bagi Pemegang Lesen dalam Kategori Kilang Buah Kelapa Sawit (MF), Kilang Penapis (RF), Pengeksport Keluaran Kelapa Sawit (PX) dan Pengimport Keluaran Kelapa Sawit (PM): Keselamatan Makanan dan Minyak Sawit yang Berkualiti, in: Berhad MPO, ed. (9)4/C/PD/656/4 Jil. 5. MPOB, Bangi, Selangor, Malaysia.
Kasmin H, Lazim AM, Awang R. 2016. Effect of heat treatments on the yield, quality and storage stability of oil extracted from palm fruits. *Malay J Anal Sci* 20(6): 1373–1381.
Kassim MSM, Ramli AR, Ismail WIW, Bejo SK. 2011. Oil palm fresh fruit bunches (FFB) growth determination system to support harvesting operation. *J Food Agric Environ* 10(2): 620–625.
Kellens M, Gibon V, Hendrix M, De Greyt W. 2007. Palm oil fractionation. *Eur J Lipid Sci Technol* 109(4): 336–349. https://doi.org/10.1002/ejlt.200600309.
Keong MS. 2017. Kegemilangan 100 tahun industri sawit dan wawasan hadapan. *Berita Harian*. Retrieved from https://www.bharian.com.my/node/283365.
Khalid K, Abbas Z. 1992. A Microstrip Sensor for Determination of Harvesting Time for Oil Palm Fruits (Tenera: Elaeis Guineensis). *J Microw Power Electromagn Energy* 27(1): 3–10. https://doi.org/10.1080/08327823.1992.11688165.
Krisdiarto AW, Sutiarso L. 2016. Study on Oil Palm Fresh Fruit Bunch Bruise in Harvesting and Transportation to Quality. *Makara J Technol* 20(2): 67–72. https://doi.org/10.7454/mst.v20i2.3058.
Krualee S, Sdoodee S, Eksomtramage T, Sereeprasert V. 2013. Correlation and path analysis of palm oil yield components in oil palm (Elaeis guineensis Jacq.). *Nat Sci* 47(4): 528–533.
Kumar P, Krishna G. 2014. Physico-chemical characteristics and nutraceutical distribution of crude palm oil and its fractions. *Grasas y Aceites* 65(2). https://doi.org/10.3989/gya.097413.
Kumaradevan D, Chuah KH, Moey LK, Mohan V, Wan WT. 2015. Optimising the operational parameters of a spherical steriliser for the treatment of oil palm fresh fruit bunch. *IOP Conf Ser: Mater Sci Eng* 88(1): 012031. Retrieved from http://stacks.iop.org/1757-899X/88/i=1/a=012031.
Kuntom A, Ai TY, Kamaruddin N, Beng YC. 2007. Pesticide application in the oil palm plantation. *Oil Palm Bull* 54: 52–67.
Lau HLN, Choo YM, Ma AN, Chuah CH. 2006. Characterization and supercritical carbon dioxide extraction of palm oil (*Elaeis Guineensis*). *J Food Lipids* 13(2): 210–221. https://doi.org/10.1111/j.1745-4522.2006.00046.x.
Lim CI, Biswas W, Samyudia Y. 2015. Review of Existing Sustainability Assessment Methods for Malaysian Palm Oil Production. *Proc CIRP* 26: 13–18. https://doi.org/10.1016/j.procir.2014.08.020.
Malaysian Standard M. 2007. Palm Oil-Specification (Second revision).
Matthäus B. 2007. Use of palm oil for frying in comparison with other high-stability oils. *Eur J Lipid Sci Technol* 109(4): 400–409. https://doi.org/10.1002/ejlt.200600294.
Mattson FH, Beck LW. 1955. The digestion in vitro of triglycerides by pancreatic lipase. *J Biol Chem* 214.
Mba OI, Dumont M-J, Ngadi M. 2015. Palm oil: Processing, characterization and utilization in the food industry – A review. *Food Biosci* 10: 26–41. https://doi.org/10.1016/j.fbio.2015.01.003.
Menon NAINR. 2017. Mitigation for 3-MCPD esters at palm oil mills. *Palm Oil Eng Bull* 124: 11–15.
Merwe GH, Plessis LM, Taylor JR. 2003. Changes in chemical quality indices during long-term storage of palm-olein oil under heated storage and transport-type conditions. *J Sci Food Agric* 84: 52–58. https://doi.org/10.1002/jsfa.1609.

Morcillo F, Cros D, Billotte N, *et al.* 2013. Improving palm oil quality through identification and mapping of the lipase gene causing oil deterioration. *Nat Commun* 4: 2160. https://doi.org/10.1038/ncomms3160.

MPOB. 2007. Code of Practice. Retrieved from http://sustainability.mpob.gov.my/?page_id=378.

MPOB. 2014. Statement on 3-MCPD Esters [Press release].

MPOB. 2015. Manual Penggredan Buah Kelapa Sawit (Manual of Oil Palm Fruit Grading). MPOB: Malaysian Palam Oil Berhad.

MPOC. The Oil Palm Tree. Retrieved from https://mpoc.eu/the-oil-palm-tree/.

Muhamad H, Ramli MI, Zakaria Z, Sahid I. 2010. Determination of Diuron in crude palm oil and rude palm kernel oil by solid phase extraction and high performane liquid chromatography using ultra violet detection from MPOB.

Muhammad H, Hashim Z, Subramaniam V, *et al.* 2010. Life cycle assessment of oil palm seedling production (Part 1). *J Oil Palm Res* 22: 878–886.

Mundi I. 2020. Palm oil production by country in 1000 MT. https://www.indexmundi.com/agriculture/?commodity=palm-oil&graph=production (Retrieved from 15/4/2020).

Muthumari GM, Thilagavathi S, Hariram N. 2016. Industrial enzymes: Lipase producing microbes from waste volatile substances. *Int J Pharmaceut Sci Res* 7(5): 2201–2208. https://doi.org/10.13040/IJPSR0975-8232.7.

Nagendran B, Unnithan UR, Choo YM, Sundram K. 2000. Characteristics of Red Palm Oil, a Carotene- and Vitamin E-Rich Refined Oil for Food Uses. *Food Nutr Bull* 21(2): 189–194. https://doi.org/10.1177/156482650002100213.

Nations and WHO. 2017. Codex Standard for Named Vegetable Oils (CODEX-STAN 210-1999). In: *Comments on discussion paper on the replacement of acid value with free fatty acids for virgin palm oils in the standard for named vegetable oils*, Malaysia.

Nazir MS, Abdullah MA, Ariwahjoedi B, Yussof AW. 2012. Hazard analysis and critical control points (HACCP) in palm oil processing to improve the productivity and food quality of palm oil vegetation in Perak, Malaysia. *Rev Científica UDO Agrícola* 12(1): 197–200.

Ngassapaa FN, Nyandoroa SS, Mwaisakab TR. 2012. Effect of temperature on the physicochemical properties of traditionally processed vegetable oils and their blends. *Tanz J Sci* 38(3): 166–176.

Norris FA. 1979. Handling storage and grading of oils and oil-bearing materials. In: Bailey AE, Swern D, Formo MW, eds. *Bailey's Industrial Oil and Fat Products*, John Wiley and Sons, pp. 479–510.

Obibuzor JU, Okogbenin EA, Abigor RD. 2012. Oil recovery from palm fruits and palm kernel. In: Lai O-M, Tan C-P, Akoh CC, eds. *Palm Oil: Production, Processing, Characterization, and Uses*. Academic Press and AOCS Press, pp. 299–328.

Odia OJ, Ofori S, Maduka O. 2015. Palm oil and the heart: A review. *World J Cardiol* 7(3): 144–149. https://doi.org/10.4330/wjc.v7.i3.144.

Okolo JC, Adejumo BA. 2014. Effect of bleaching on some quality attributes of cude palm oil. *IOSR J Eng (IOSRJEN)* 04(12): 25–28.

Oo KC, Teh SK, Khor HT, Ong ASH. 1985. Fatty acid synthesis in the oil palm (*Elaeis guineensis*): Incorporation of acetate by tissue slices of the developing fruit. *Lipids* 20(4): 205–210.

Owolarafe OK, Osunleke AS, Odejobi OA, Ajadi SO, Faborode MO. 2008. Mathematical modelling and simulation of the hydraulic expression of oil from oil palm fruit. *Biosyst Eng* 101(3): 331–340. https://doi.org/10.1016/j.biosystemseng.2008.08.007.

Paradiso VM, Gomes T, Nasti R, Caponio F, Summo C. 2010. Effects of free fatty acids on the oxidative processes in purified olive oil. *Food Res Int* 43(5): 1389–1394. https://doi.org/10.1016/j.foodres.2010.04.015.

Poku K. 2002. Small-scale palm oil processing in Africa. *Fao Agric Services Bull* 148.

Pudel F, Benecke P, Fehling P, Freudenstein A, Bertrand M, Schwaf A. 2011. On the necessity of edible oil refining and possible sources of 3-MCPD and glycidyl esters. *Eur J Lipid Sci Technol* 113: 368–373.

Ramli MR, Siew WL, Ibrahim NA, Kuntom A, Abd Razak RA. 2015. Other factors to consider in the formation of chloropropandiol fatty esters in oil processes. *Food Additives Contaminants: Part A* 32(6): 817–824. https://doi.org/10.1080/19440049.2015.1032368.

Ramli NAS, Mohd NMA, Musa H, Ghazali R. 2017. Stability evaluation of quality parameters for palm oil products at low temperature storage. *J Sci Food Agric* 98(9): 3351–3362. https://doi.org/10.1002/jsfa.8839.

Rangkuti IUP, Julianti E, Elisabeth J. 2018. The tocol content of crude palm oil based on the level ripeness and their relationship to the quality and their stability. *IOP Conf Ser: Earth Environ Sci* 122. https://doi.org/10.1088/1755-1315/122/1/012081.

Razali MH, Ishak WIW, Rahman RA, Nasir SM, Haniff HM. 2009. Development of image based modeling for determination of oil content and days estimation for harvesting of fresh fruit bunches. *Int J Food Eng* 5(2): 12–30.

Rival A, Montet D, Pioch D. 2016. Certification, labelling and traceability of palm oil: can we build confidence from trustworthy standards? *OCL* 23(6). https://doi.org/10.1051/ocl/2016042.

Sambanthamurthi R, Cheang OK, Parman SH. 1995. Factors Affecting Lipase Activity in the Oil Palm (Elaeis Guineensis) Mesocarp. In: Kader J-C, Mazliak P, eds. *Plant Lipid Metabolism*. Dordrecht, Netherlands: Springer, pp. 555–557.

Sambanthamurthi R, Chong CL, Oo KC, Rajan P, Yeo KH. 1991. Chilling-induced lipid hydrolysis in the oil palm (Elaeis guineensis) mesocarp. *J Exp Bot* 42(9): 1199–1205. https://doi.org/10.1093/jxb/42.9.1199.

Sambanthamurthi R, Rajanaidu N, Parman SH. 2000. Screening for lipase activity in the oil palm. *Biochem Soc Trans* 28(6): 769. Retrieved from http://www.biochemsoctrans.org/content/28/6/769.abstract.

Sambanthamurthi R, Singh R, Kadir APG, Abdullah MO, Kushairi A. 2009. Opportunities for the oil palm via breeding and biotechnology. *Breed Plant Tree Crops: Trop Spec* 377–421. https://doi.org/10.1007/978-0-387-71201-7_11.

Sambanthamurthi R, Sundram K, Tan Y-A. 2000. Chemistry and biochemistry of palm oil. *Progr Lipid Res* 39(6): 507–558. https://doi.org/10.1016/s0163-7827(00)00015-1.

Santos MFG, Alves R, Roca M. 2015. Carotenoid composition in oils obtained from palm fruits from the Brazilian Amazon (Vol. 66).

Sharip Z, Hashim N, Suratman S. 2017. Occurrence of organochlorine pesticides in a tropical lake basin. *Environ Monit Assess* 189(11): 560. https://doi.org/10.1007/s10661-017-6274-y.

Sheil D, Casson A, Meijaard E, *et al.* 2009. The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? Vol. 51. Bogor, Indonesia: Center for International Forestry Research.

Sivasothy K, Halim RM. 2000. Continuous sterilization of fresh fruit bunches – Part 2. *Eng News* 57: 11–17.

Sivasothy K, Halim RM, Basiron Y. 2005. A new system for continuous sterilization of oil palm fresh fruit bunches. *J Oil Palm Res* 17: 145–151.

Spaparin N, Krishnan A, Noor AM. 2017. MPOB.
Subramaniam V, May CY, Muhammad H, Hashim Z, Tan YA, Wei PC. 2010. Life cycle assessment of the production of crude palm oil (Part 3). *J Oil Palm Res* 22: 895–903.
Supriyono J. 2018. Sejarah Kelapa Sawit Indonesia. Retrieved from https://gapki.id/news/3652/video-sejarah-kelapa-sawit-indonesia.
Syahro N, Yunus R, Abidin ZZ, Syafiie S. 2015. Modeling and simulation of heat and mass transfer in oil palm fruit digestion process. *J Emerg Trends Eng Appl Sci* 6(2): 136–143.
Tagoe SMA, Dickinson MJ, Apetorgbor MM. 2012. Factors influencing quality of palm oil produced at the cottage industry level in Ghana. *Int Food Res J* 19(1): 271–278.
Tan CH, Ariffin AA, Ghazali HM, *et al.* 2017. Changes in oxidation indices and minor components of low free fatty acid and freshly extracted crude palm oils under two different storage conditions. *J Food Sci Technol* 54(7): 1757–1764. https://doi.org/10.1007/s13197-017-2569-9.
Tarmizi AHA, Razak RAA, Hammid ANA, Kuntom A. 2019. Effect of Anti-Clouding Agent on the Fate of 3-Monochloropropane-1,2-Diol Esters and Glycidyl Esters in Palm Olein during Repeated Frying. *Molecules* 24(12). https://doi.org/10.3390/molecules24122332.
Teng WY, Kushairi A, Rajanaidu N, Osman M, Ratnam W, Sambanthamurthi R. 2015. Screening of wild oil palm (Elaeis guineensis) germplasm for lipase activity. *J Agric Sci* 154(7): 1241–1252. https://doi.org/10.1017/S0021859615001112.
Tombs MP, Stubbs JM. 1982. The absence of endogenous lipase from oil palm mesocarp. *J Sci Food Agric* 33(9): 892–897. https://doi.org/10.1002/jsfa.2740330912.
Wahab NA, Aziz AA, Berahim N, *et al.* 2017. The quality of oil extracted from palm pressed fibre using aqueous enzymatic treatment. *J Oil Palm Res* 29: 588–593.
Wong YH, Lai OM, Abas F, *et al.* 2017. Factors impacting the formation of 3MCPD esters and glycidyl esters during deep fat frying of chicken breast meat. *J Am Oil Chem Soc* 94(6): 759–765. https://doi.org/10.1007/s11746-017-2991-1.
Xu T-T., Li J, Fan Y-W., Zheng T-W., Deng Z-Y. 2014. Comparison of Oxidative Stability among Edible Oils under Continuous Frying Conditions. *Int J Food Prop* 18(7): 1478–1490. https://doi.org/10.1080/10942912.2014.913181.
Yamamoto K, Haneishi K. 2014. E.P. Application.
Yassin NMFM. 2018. Washing of CPO – Sime Darby Experience. Mini Seminar on Enhancing the Midstream and Downstream Sectors for Palm Oil: Updates and The Way Forward on 3-MCPDE/GE and Biogas Implementation. Bandar Baru Bangi, Selangor, Malaysia: Malaysia Palm Oil Berhad (MPOB).
Yoshida H, Kono U, Kajimoto G. 1992. Participation of free fatty acids in the oxidation of purified soybean oil during microwave heating. *J Am Oil Chem Soc* 69: 1136–1140.
Zulkefli F, Othman N, Syahlan S, Zaini MR, Bakar MA. 2017. Fresh fruit bunch quality and oil losses in milling processes as factors that affect the extraction rate of palm oil. *Int J Agric Forest Plant* 5: 99–103.
唐应彪, 崔新安, 袁海欣, *et al.* (Tang YB, Cui X, Yuan HX, *et al.*). 2019. China Patent No. CN105368580A 中.集.股.中石化洛阳工程有 限公司 (Sinopec Luoyang Engineering Co., Ltd.).

Cite this article as: Nizam AFA, Mahmud MS. 2021. Food quality assurance of crude palm oil: a review on toxic ester feedstock. *OCL* 28: 23.