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Palm oil: Processing, characterization and utilization in the food industry – A review



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ABSTRACT

The oil palm tree is an ancient tropical plant that originated from West Africa. Palm oil has centuries' long use as food and medicine. This review covers the recent significant materials found in the literature on palm oil processing, refining, and use in frying especially in blends with other vegetable oils. Crude palm oil (CPO) is obtained from the fruit of the oil palm tree (*Elaeis guineensis*). The oil is rich in palmitic acid, β -carotene and vitamin E. CPO has been fractionated mainly into liquid palm olein and solid palm stearin in order to diversify its food applications. Palm oil is highly stable during frying especially due to the synergistic activity of β -carotene and tocotrienol. In recent years there has been a shift from the use of animal fats and hydrogenated vegetable oils in frying and other food applications. The use of naturally stable oils such as palm oil and composite oils like blends of palm oil and other fats and oils is practiced to ensure that maximum benefits are derived from the oils. Blending offers functional, nutritional and technical advantages, such as tailoring the oil to suit frying applications. The objective of this review is to combine and condense the body of research on the processing, characterization and use of palm oil especially in frying as well as suggest areas that need further research.

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Nutrients
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1. Introduction

Palm oil is extracted from the ripened mesocarp of the fruits of oil palm tree (*Elaeis guineensis*). The oil palm fruit is a drupe formed in spiky tight bunches. The five leading producing countries are Indonesia, Malaysia, Thailand, Colombia and Nigeria. The oil palm tree gives the highest yield of oil per unit area of cultivated land, an estimated 58.431 million metric tons (MT) per year. One hectare of oil palm plantation is able to produce up to 10 times more oil than other leading oilseed crops. Palm fruit produces two distinct types of oils: crude palm oil (CPO) from the mesocarp and palm kernel oil (PKO) from the inside kernel (Gourichon, 2013; Robbelen, 1990). Both CPO and PKO are important in world trade (Schroeder, Becker, & Skibsted, 2006). In 2012, CPO and PKO accounted for 32% of global fats and oils production. Palm oil has overtaken soybean oil as the most important vegetable oil in the world (Oil World, 2013). A chart showing the recent supply of vegetable oils in the world's market is shown in Fig. 1. CPO is also called red palm oil because of its high content of carotenoids. It is a rich source of vitamin E (600–1000 ppm); coenzyme Q10 (ubiquinone) (18–25 mg/kg) and sterols (325–365 mg/kg) (Tyagi & Vasishtha, 1996). The edible food industry utilizes about 90% of palm oil, while the remaining 10% finds application in soap and oleochemical manufacturing (Oil World, 2013).

Palm oil has a unique fatty acid (FA) and triacylglycerol (TAG) profile which makes it suitable for numerous food applications. It is the only vegetable oil with almost 50–50 composition of saturated and unsaturated fatty acids. CPO is used for cooking, frying, and as a source of vitamins. Fractionation of CPO yields mainly palm olein, the liquid fraction and palm stearin, the solid fraction. These fractions have distinct physical and chemical properties. CPO, palm olein and palm stearin are important constituents of several food and industrial products such as shortenings, ice cream,

cosmetics, candles lubricants, toothpaste and biodiesel (Barriuso, Astiasarán, & Ansorena, 2013). Palm stearin is helpful in providing the solid fat functionality without the use of hydrogenation, thus reducing trans-fat intake in the diets (Kellens, Gibon, Hendrix, & De Greyt, 2007). Interesterification of CPO also widens its scope of food applications. Interesterification can be used to incorporate essential polyunsaturated fatty acids in order to obtain oil rich in essential fatty acids and enhanced antioxidant properties. Customized blends of CPO and fractions with other oils are used in different food products ranging from margarines to soup mixes and infant formulae (Manorama & Rukmini, 1992).

Palm oil is top prime among frying oils. In addition to its unique fatty acid composition, it has a high smoke point of about 230 °C. Frying is an ancient cooking method that started probably around the 6th Century BC (Gupta, 2004; Kochhar, 2001; Morton, 1998). Frying heats the food through to the middle, cooking the interior and creating a 'crust' on the surface of the food plus a characteristic fried food flavor (Marikar, Ghazali, Long, & Lai, 2003; Rossell, 2001). The hot oil serves as a medium of heat and mass transfer. During frying, some of the oil is absorbed by the product, while moisture in the form of vapor is given off. Thus, frying combines cooking and drying. Important chemical and physical changes occur during frying. Examples are starch gelatinization, protein denaturation, water vaporization and crust formation (Krokida, Oreopoulou, & Maroulis, 2000; Saguy & Dana, 2003). Fried food quality is a function of oil quality. The degradation of cooking oils affects the texture, taste, and overall flavor perception of the food (Stier, 2013).

Berger (2005) reviewed the performance of palm oil and palm olein in frying. The focus of the review was the suitability and stability of palm oil in restaurant batch fryers and continuous frying in the manufacture of snack foods. Matthaues (2007), in his review, concluded that palm oil and the byproducts of palm oil have similar frying performance

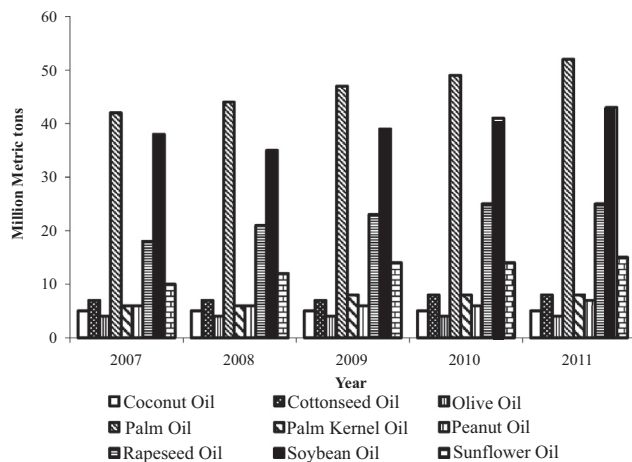


Fig. 1 – World supply of vegetable oils.

when compared to high oleic oils. This review aims at highlighting and evaluating the physicochemical characteristics, nutritional, functional and frying qualities of palm oil. It also focuses on the processing, refining and characterization of palm oil. The suitability and sustainability of blending CPO with other unsaturated vegetable oils for use in the food service and processing industries as a cost effective and healthy alternative to partial hydrogenation will be explored.

2. Processing and refining

The mesocarp of palm fruits contains about 56–70% edible oil when fully ripened. This oil can be extracted using different methods. These methods are grouped into four categories based on their throughput and degree of complexity. They are the traditional methods, small-scale mechanical units, medium-scale mills and large industrial mills (Poku, 2002). The basic unit operations associated with palm oil processing include fruit sterilization, fruit loosening/stripping, digestion, oil extraction and clarification. Fruit sterilization denotes heat rendering and moisture absorption. The aim is to inactivate the lipolytic enzymes in the fruit mesocarp. The two major extraction procedures are mechanical pressing and solvent extraction. Oil extraction efficiency range of 75–90% has been reported for mechanical screw presses (Owolarafe, Faborode, & Ajibola, 2002; Poku, 2002). CPO obtained by either mechanical pressing or solvent extraction contains desirable and undesirable compounds. Desirable compounds include triacylglycerols (TAGs) (neutral lipids) and health beneficial compounds such as the vitamins E (tocopherols and tocotrienols), carotenoids and phytosterols. The desired compounds serve as nutrients, antioxidants and health beneficial compounds. Free fatty acids (FFAs), phospholipids (PLs) or gums, and lipid oxidation products are the major undesirable compounds. The impurities are objectionable from a sensory point of view (Čmolík & Pokorný, 2000; Dunford, 2012). The impurities are removed during oil refining process (Sambanthamurthi, Sundram, & Tan, 2000).

The most common methods of palm oil extraction are either the ‘wet’ or the ‘dry’ processes. In the ‘wet’ process a

liquid, usually water, is used to extract the oil from the milled palm fruits. Hot water or steam is used to leach out the oil from ruptured oily cells of the palm fruits. The hot water treatment also hydrolyzes gums, resins and any starch present as well as coagulates proteins. The gums and resins cause the oil to foam during frying. The hydrolyzed and coagulated products are removed during oil clarification. The extracted oil is recovered after evaporating the moisture (Obibuzor, Okogbenin, & Abigor, 2012; Poku, 2002). In the ‘dry’ method, a hydraulic press or a screw press or centrifugation is employed. The screw press is generally more applicable in continuous extraction systems while the hydraulic press is commonly used in batch or semi-batch extraction systems (Poku, 2002). During pressing, the crude palm oil drains from the fibrous mesocarp leaving behind fiber materials that still retains about 5–6% of oil. In order to avoid cracking the palm kernels, the pressure is normally reduced and oil retention increases to 10–12% (Corley & Tinker, 2003; Obibuzor et al., 2012). The resulting press liquor is a mixture of water, oil, dirt, and fruit debris in varying concentrations. The liquor is processed further to maximize oil yield and reduce the moisture content in the CPO to $\leq 10\%$ (Poku, 2002). This process, besides being critical to the quality of the CPO, leads to oil loss and environmental pollution. After most of the oil has been recovered, palm oil mill effluent (POME) is left behind. More oil can be recovered from POME when food grade solvents such as hexane and petroleum ether are used for the oil extraction (Obibuzor et al., 2012). The CPO stock is further purified by centrifugation and drying. Vacuum drying has been suggested to avoid further degradation of the oil quality, especially the FFA content. The dried oil is then cooled and pumped to storage tanks or other suitable containers (Bassim, Abdul, & Ng, 2003; Obibuzor et al., 2012). Norhuda and Mohd Omar (2009) reported the feasibility of using supercritical carbon dioxide extraction method for the extraction of CPO. This is more applicable for the extraction of PKO from the crushed kernels. Similarly, solvent extraction process is used in high capacity mills for PKO extraction. It involves three main unit operations: kernel pre-treatment, oil extraction, and solvent recovery from the oil and meal. Poku (2002) reported that the yields and quality of the extracted oil depend on the initial oil and moisture contents, operating temperature, heating time and the applied pressure.

The crude oil is usually washed with a solution of sodium hydroxide or sodium carbonate to reduce the FFAs content, remove the PLs and other polar lipids. This operation is generally referred to as alkali refining. Alkali refining alone cannot remove all objectionable compounds that may be present (Čmolík & Pokorný, 2000). Other refining procedures and targeted impurities are shown in Table 1. Dunford (2012) reported a refining process involving heating the crude oil with water or an aqueous solution of phosphoric acid. The gums are subsequently removed by centrifugation. Pigments are removed by bleaching with activated clay or charcoal, while volatile oxidation products are removed through steam distillation at high temperatures and reduced pressure. The resulting oil is usually colorless, bland, and has good storage stability (Čmolík & Pokorný, 2000; Dunford, 2012). Čmolík and Pokorný (2000) reported that the disadvantages of alkali refining include: losses of neutral triacylglycerols, high

Table 1 – Refining operation and target impurities.

Source: Aparicio and Harwood (2013) Čmolík and Pokorný (2000)

Refining operation	Targeted impurity
Hydration/degumming	Phospholipids; other polar lipids (gums)
Neutralization	Free fatty acids; residual phospholipids; metals
Bleaching	Pigments; residual soaps; phospholipids
Deodorization	Volatile oxidation products; other contaminants

energy requirement, high cost of equipment, time consuming, and generates large amounts of effluents that pollutes the environment. For these reasons, physical methods of refining are recommended. Physical refining is based on the higher volatility of FFAs and TAGs at high temperatures and low pressures. During physical refining, volatile compounds including FFAs are volatilized and neutral oil droplets are carried in the current of the stripping steam. These methods include: steam refining, inert gas stripping, molecular distillation, membrane refining, hermetic system, supercritical carbon dioxide, etc. (Dunford, 2012; Gunstone, 2011).

The quality of extracted palm oil determines the grades and the premium payable. Generally, palm oil with low FFA and moisture content, very low levels of impurities and good bleachability index is considered to be of high quality. The quality of palm oil dictates and directs its use. Broadly speaking, high quality palm oils are used in the edible oil industry while lower quality oils are used in the non-edible industry for biofuels, candles, cosmetics and soap (Henson, 2012). Good quality oil contains more than 95% neutral TAGs and 0.5% or less FFA. As an industry rule, the FFA content of refined oils must be $\leq 0.1\%$. Most crude oils usually contain 1–3% of FFA. Where the oil has high FFA, physical refining is recommended (Dunford, 2012; Gunstone, 2011). CPO containing 12% FFA has been reduced to 1.3% FFA at 220 °C and 0.5% FFA at 230 °C by physical refining at a pressure of 0.8 kPa (Čmolík & Pokorný, 2000). However, care must be taken since high temperatures lead to destruction of carotenes. The consequence is oil with reduced nutritional quality and color. Lower deodorization temperatures are recommended (Aparicio & Harwood, 2013). A two-step process for refining CPO has also been reported. This involved acidifying to remove PLs and other gums and steam stripping at lower temperatures (180 °C and 200 °C). This procedure yielded oils with satisfactory flavor. Steam stripping at higher temperatures 240–270 °C at 0.25–1.32 kPa has been reported (Derksen & Cuperus, 1998). The effectiveness of two modern deodorization devices, Mellapak[®] and Optiflow[®], which guarantee satisfactory mass transfer and a substantially improved steam distribution have been reported (Čmolík & Pokorný, 2000; Faessler, 1998). The red color of palm oil is generally accepted by the consumers. High carotene content is desirable because of its pro vitamin A and antioxidant activities. Ooi, Choo, Yap, and Ma (1996) proposed the use of a molecular distillation unit which reduces the FFA content of CPO to $\leq 0.1\%$, while retaining more than 80% of the carotenes and tocopherols.

Sometimes, the food service and manufacturing industries require CPO with bland and light color. CPO can be refined by

the chemical or physical process to meet that requirement. The major unit operations in CPO refining are shown in Fig. 2. The difference between the two processes is that the acid neutralization step is omitted in the physical refining process where the FFAs are removed at the deodorization step. Chemical refining is carried out at a lower temperature and shorter time. Losses of tocopherols, tocotrienols and oxidative damage are higher in the physical refining process especially if air leakage occurs during the process. Physically refined oils have lower storage stability. In physical refining, it is important to eliminate phosphorus as much as possible during the degumming step and to prevent phosphoric acid slip-through, as this would affect the efficiency of heat bleaching later on in the process (Chong, 2012; Dunford, 2012).

The utilization of most natural vegetable oils can be diversified through physical and chemical modification procedures. One such modification process is fractionation. Fractionation is a selective physical and/or thermo-mechanical process that separates a mixture into two or more fractions with distinct physical and chemical properties. It is a fully reversible modification process. Oils are fractionated to change the physicochemical properties of the oil such as reducing the degree of unsaturation of the acyl groups. This is done by redistributing the fatty acids chains using different selective crystallization and filtration methods (Kellens et al., 2007). The separation is based on differences in solidification, solubility, or volatility of the constituents. CPO is fractionated based on the differences in the crystallization behavior of the TAGs. CPO easily separates into a low melting liquid fraction (65–70% palm olein) and a high melting solid fraction (30–35% palm stearin). The products mainly have different iodine values (IV). There are three different types of fractionation: dry fractionation, detergent fractionation, and solvent fractionation (Kellens et al., 2007; Pande, Akoh, & Lai, 2012). Fractionation adds value to the oil and creates no undesirable byproducts. Table 2 gives a summary of the advantages and disadvantages of the refining and fractionation methods.

The importance and uses of palm oil, palm olein, and palm stearin are well discussed by Kellens et al. (2007) and their health effects by Sambanthamurthi et al. (2000). These major fractions, like CPO can also be refined, bleached and deodorized (RBD). RBD palm olein is used in frying, cooking, shortenings and margarines. RBD palm stearin is used mainly in food applications that require higher solid fats content such as shortenings, margarines and vanaspati (hydrogenated vegetable oils used as substitute for butter in South Asia especially India). Other fractions such as PMF are used as

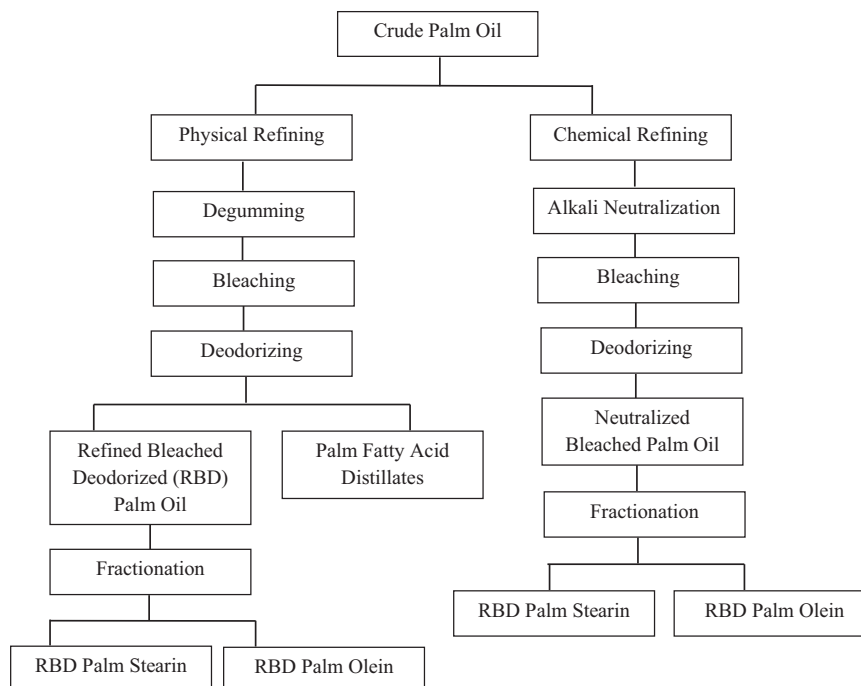


Fig. 2 – Palm oil refining process.

cocoa butter equivalents in confectioneries while super olein (double fractionated palm olein) is used in mayonnaise and salad dressings (Sarmidi, El Enshasy, & Hamid, 2009). While olive, rapeseed and canola oils contain $\geq 60\%$ of cis-oleic acid, palm olein has $\approx 48\%$ of oleic acid. It has been reported that in healthy normocholesterolaemic humans, palm olein could be substituted for olive oil without adversely affecting serum lipids and lipoprotein levels since it is rich in oleic acid (Sambanthamurthi et al., 2000).

3. Characterization

The most commonly used method for the determination of total fats in dried food samples is Soxhlet extraction. There are also instrumental techniques and procedures adapted from pharmaceutical and chemical engineering analyses protocols. The extraction technique is simpler, more accurate and more generally applied in lipid analyses than the instrumental methods. However, extraction techniques are time consuming, destructive and generate large volumes of laboratory effluents that lead to disposal challenges. On the other hand, instrumental techniques are non-destructive, give rapid useful results for online quality measurements in laboratories and food factories. Due to the chemical nature of vegetable oils, most standard methods recommend that they be characterized using Soxhlet methods. Recent analytical procedures such as chromatography and spectroscopy [Gas Chromatography-Flame Ionization Detector (GC-FID); Gas Chromatography-Mass Spectroscopy (GC-MS) and High Performance Liquid Chromatography (HPLC)], which are based on physics rather than chemistry (Gunstone, 2011) are increasingly being used

for vegetable oils' characterization. The use of procedures such as thermogravimetric analysis (TGA) (Debnath, Raghavarao, & Lokesh, 2011), differential scanning calorimetry (DSC) (Marquez & Maza, 2003; Tan & Man, 2000), Fourier transform infrared (FTIR) and Fourier transform near-infrared (FTNIR) spectroscopy have been reported as well (Azizian, Kramer, & Winsborough, 2007; Casale, Casolino, Ferrari, & Forina, 2008; Mba, Adewale, Dumont, & Ngadi, 2014).

International organizations such as those listed below provide similar but not identical techniques, methods, procedures and protocols for the analysis of lipid samples. The guidelines differ as efforts continue to be made to ensure accuracy and precision of outcomes; and more sensitive test tools continue to evolve. The procedures require that the test sample must be a true representative of the target oil sample (s). Guidelines also exist for transport and storage of the lipid samples before analysis. In order to ensure the reliability of the analytical results, care must be given to details such as the storage temperature, the type of container and the possible addition of antioxidants (Gunstone, 2011; Stier, 2004). The organizations providing guidelines include

- The Association of Official Analytical Chemists (AOAC),
- The American Oil Chemists' Society (AOCS),
- The British Standards Institution (BSI),
- The International Organization for Standardization (ISO),
- The International Union of Pure and Applied Chemists (IUPAC),
- German Society for Fat Research (DGF),
- Palm Oil Research Institute of Malaysia (PORIM),
- American Society for Testing of Materials (ASTM), and
- Codex Alimentarius Commission for Oils and Fats.

Table 2 – Advantages and disadvantages of different refining and fractionation methods.

Source: Čmolík and Pokorný (2000) Dumont and Narine (2007) Kellens et al. (2007)

Operation	Advantages	Disadvantages
Refining		
Chemical	(1) Functional process (2) Great reduction of FFA	(1) Losses of neutral TAGs (2) High energy requirement (3) Very expensive (4) Time consuming (5) Generates polluting effluents
Physical	(1) Less energy requirement (2) Less by products generated (3) Reduced cost	(1) Destruction of carotenes (2) Loss of deep red color (3) High oxidative damage (4) Likely loss of Vitamins E (5) Reduced storage stability
Fractionation		
Dry	(1) Simple (2) Cheap (3) No chemicals (4) No effluent (5) No losses (6) No additional substance (7) Multi-step operation possible	(1) Viscosity problems (2) Limited degree of crystallization
Detergent	(1) Crystals easily suspended in the aqueous phase	(1) Very expensive (2) Risk of product contamination (3) Requires additional accessories
Solvent	(1) Reduced viscosity (2) Short process time (3) High separation efficiency (4) Improved yield (5) Higher purity of products	(1) High capital investments (2) High production costs (3) Possible fire hazards (4) Hazardous chemicals and effluents

3.1. Physicochemical characterization of palm oil

The Mongana report of 1955 was one of the earliest comprehensive research works on palm oil characterization. It dealt with palm oil milling and CPO quality in Africa. Then, CPO quality was mainly defined in terms of total percentage of FFA, moisture and impurities. After the Second World War, a more complex quality grading system was introduced to regulate oil production by cottage industries. A five point grading system was introduced. 'Grade 1' oils must have FFA < 1% while 'grade 5' oils have FFA > 36%. 'Grades 2, 3 and 4' oils have FFA ranges of 9–18%, 18–27%, and 27–36%, respectively. This grading system stimulated the small scale producers to improve their oil quality. Later, the specification 'Special Grade' palm oil with maximum FFA level of 4.5% at the point of sale was introduced. Further adjustment put the maximum FFA at 3.5%. Trade reports showed that by 1965 more than 80% of CPO export from Africa was of the 'Special Grade' quality (Berger & Martin, 2000; Iwuchukwu, 1965). Since the 1990s, some countries such as Malaysia have the set limits of FFA to ≤ 5% and a maximum of 0.25% for moisture and impurities for locally produced CPO (Chong, 2012).

The physicochemical properties of palm oil and its fractions were extensively studied during the 1980s and 1990s.

Brilliant works on the physicochemical properties of palm oil and its fractions have been published (Tan & Oh, 1981; Tan & Man, 2000; Tan & Nehdi, 2012). CPO is classified as saturated oil with iodine value (IV) range of 51–58 g/100 g oil. Palm oils with a wider IV range of 46–63 g/100 g oil have been reported. These types of palm oil may be mixtures of oils from different species of oil palm tree or oil mixed with various proportions of palm stearin (Edem, 2002; Elias & Pantzaris, 1997; O'Brien, 2010; Tavares & Barberion, 1995). The major physicochemical characteristics of palm oil are presented in Table 3.

3.2. Fatty acid characterization

When compared to other vegetable oils, CPO has a unique fatty acid composition (FAC). FAC analysis is the most widely practiced analytical technique in lipid science. The FAC of palm oil has been widely reported by many researchers (Almeida et al., 2013; Che Man, Setiowaty, & Van de Voort, 1999; O'Brien, 2010; Tan & Nehdi, 2012). The mixed triacylglycerols are derivatised to methyl or silyl esters and subsequently separated and identified using appropriate gas chromatography column and protocol (Christie, 1993; Durant, Dumont, & Narine, 2006; Gunstone, 2011).

Table 3 – Physicochemical properties of palm oil.

Characteristics	Typical	Range	Reference/source
Apparent density at 50 °C (g/ml)	–	0.892–0.899	O'Brien (2010), Codex Alimentarius (1999)
AOM stability (h)	54.0	53.0–60.0	O'Brien (2010)
Melting point (°C)	37.5	33.0–45.0	O'Brien (2010), Firestone (2006)
Oxidative stability index at 110 °C (h)	16.9	16.6–19.0	O'Brien (2010)
Refractive index at 50 °C	–	1.449–1.456	O'Brien (2010), Firestone (2006)
Smoke point (°C)	–	230.0–235.0	Gunstone (2011)
Solidification point (°C)	–	35.0–42.0	O'Brien (2010)
Solid fat content			
10 °C	34.5	30.0–39.0	O'Brien (2010)
21.1 °C	14.0	11.5–17.0	O'Brien (2010)
26.7 °C	11.0	8.0–14.0	O'Brien (2010)
33.3 °C	7.4	4.0–11.0	O'Brien (2010)
37.8 °C	5.6	2.5–9.0	O'Brien (2010)
40.0 °C	4.7	2.0–7.0	O'Brien (2010)
Specific gravity at 50 °C	–	0.888–0.889	O'Brien (2010)
Viscosity (cP)	45.0	45.0–49.0	Berger (2005)
Iodine value (g/100 g)	53.0	46.0–56.0	O'Brien (2010), Edem (2002)
Free fatty acid (% FFA as palmitic)	–	3.17–5.0	Chong (2012)
Peroxide value (meqO ₂ /kg)	–	0.1–10.0	O'Brien (2010)
Anisidine value (mg KOH/g)	–	0.6–4.65	Chong (2012)
Saponification value (mg KOH/g)	196.0	190.0–209.0	O'Brien (2010), Chong (2012)
Unsaponifiable matter (%)	0.5	0.15–0.99	O'Brien (2010)
Total polar compounds (%)	13.5	9.47–19.50	Almeida et al. (2013), Berger (2005)
Total polymer materials (%)	0.5	0.4–15.0	Berger (2005)
Saturated fatty acids SFA (%)	–	49.9–54.7	Tan and Nehdi (2012)
Mono-unsaturated fatty acids MUFA (%)	–	37.1–39.2	Gunstone (2011), Tan and Nehdi (2012)
Poly-unsaturated fatty acids PUFA (%)	–	8.1–10.5	Gunstone (2011), Tan and Nehdi (2012)
Crystal habit	β'	–	O'Brien (2010)

The near equal composition of saturated fatty acids (SFA) and unsaturated fatty acids (UFA) in CPO makes it naturally semi solid at room temperature. CPO has a high level of palmitic acid (C16:0) which accounts for approximately 44% of the FAC. The other major fatty acids are oleic acid (C18:1), linoleic acid (C18:2) and stearic acid (C18:0) accounting for 40%, 10% and 5%, respectively (Tan & Man, 2000). Similar to other vegetable oils, CPO and its fractions, namely palm olein; palm stearin; and superolein are comprised of mixed triacylglycerols (TAGs) and partial acylglycerols, such as diacylglycerols (DAGs) and monoacylglycerols (MAGs). DAGs and MAGs are hydrolysis products of TAGs that can affect the melting point and crystallization behavior of the oil (Foster, Williamson, & Lunn, 2009). Partial acylglycerols can cause cloudiness at concentrations above 10% especially when temperatures drop below 20 °C (Berger, 2007). The fatty acid and glyceride composition of palm oil is shown in Table 4.

Choe and Min (2007) reported that the range of TGAs in CPO and fractions are 94–98%; DAGs 5–8%; MAGs 0.21–0.34%; and FFA 2–5%. Poor storage and handling conditions can lead to increased values due to hydrolytic breakdown. The remaining 1% consists of the minor components, namely, carotenes, tocopherols and tocotrienols, sterols and squalene (Berger, 2007). The type of TAG is determined by its FA composition, the distribution of the FAs in the TAG molecule, the proportions of the individual FAs, the source of the oil, and the processing history (Foster et al., 2009; Ghotra, Dyal, & Narine, 2002). The TAGs can be further grouped into four categories: trisaturated (SSS); disaturated–monounsaturated (SSU); monosaturated–diunsaturated (SUU); and triunsaturated (UUU). Tan and Man (2000) reported that these four TAG

groups and more than 33 TAG molecular species can be found in palm oil. The structurally symmetrical POP, POO, PPO, PLO, and PLP are the major ones (P=palmitic; O=oleic; and L=linoleic).

Scores of research and review articles published within the last decade agree that the principal triacylglycerol species in palm oil is palmitic acid. The majority of the palmitic acid is located at the outer *sn*-1 and *sn*-3 positions of the glycerol molecule. However an estimated 13–23% palmitic acid of CPO is found at the *sn*-2 position (Andreu-Sevilla, Hartmann, Burlo, Poquet, & Carbonell-Barrachina, 2009; Atinmo & Bakre, 2003; Berger, 2005; Curvelo, Almedia, Nunes, & Feitosa, 2011; Gebauer, Harris, Kris-Etherton, & Etherton, 2005; Hayes & Khosla, 2007; Ismail, 2005; Pande et al., 2012; Stier, 2013; Sundram, Sambanthamurthi, & Tan, 2003; Tan & Nehdi, 2012). In infant feeding and formulae preparation, there is better absorption and energy release in having palmitic acid at the *sn*-2 position (Innis, 2011; Ramirez, Amate, & Gil, 2001). Filippou, Berry, Baumgartner, Mensink, and Sanders (2014), reported that dietary TAGs with an increased proportion of palmitic acid in the *sn*-2 position do not have acute adverse effects on the insulin and glucose response to meals in healthy adults. The FAC profile of CPO is significantly different from that of PKO, which is made up of 85% SFA, mainly lauric acid (Sambanthamurthi et al., 2000). Largely, there is no significant difference in the FAC of palm oil obtained from different geographical zones (Tan, Ghazali, Kuntom, Tan, & Ariffin 2009). However, Lin (2011) reported that the composition of Nigerian palm oil shows considerably larger variation. Palmitic acid range is 27–55%; oleic acid 28–56% and linoleic acid 6.5–18%. These variations serve as

Table 4 – Fatty acid and glyceride composition of palm oil.

Compound	Typical	Range ^a	Range ^b
Fatty acid composition (%)			
Lauric acid (C12:0)	0.0 ^a	0.1–1.0	0.0–0.4
Myristic acid (C14:0)	1.1 ^a	0.9–1.5	0.5–2.0
Palmitic acid (C16:0)	44.0 ^a	41.8–46.8	40.0–48.0
Palmitoleic acid (C16:1)	0.1 ^a	0.1–0.3	0.0–0.6
Stearic acid (C18:0)	4.5 ^a	4.5–5.1	3.5–6.5
Oleic acid (C18:1)	39.2 ^a	37.3–40.8	36.0–44.0
Linoleic acid (C18:2)	10.1 ^a	9.1–11.0	6.5–12.0
Linolenic acid (C18:3)	0.4 ^a	0.4–0.6	0.0–0.5
Arachidic acid (C20:0)	0.4 ^a	0.2–0.7	0.0–1.0
Triglyceride composition (%)			
Trisaturated (SSS)	9.8 ^c	0.8–9.0	–
Disaturated (SUS)	48.8 ^c	38.5–50.3	–
Monosaturated (SUU)	36.5 ^c	31.8–44.4	–
Triunsaturated (UUU)	4.8 ^c	4.8–9.8	–
Diglycerides (%)	4.9 ^a	3.0–7.6	–

^a O'Brien (2010).^b Firestone (2006).^c Tan and Nehdi (2012).**Table 5 – Micronutrients and other minor components of palm oil.**

Micronutrient/component	Range (ppm)
Carotenoids	
α-Carotene	30.0–35.16 ^b
β-Carotene	50.0–56.02 ^b
Lycopene	1.0–1.30 ^b
Total carotenoids	500–700 ^b
Tocopherol	
α-Tocopherol	129–215 ^a
β-Tocopherol	22–37 ^a
γ-Tocopherol	19–32 ^a
δ-Tocopherol	10–16 ^a
Total tocopherol	500–600 ^a
Tocotrienols	
α-Tocotrienol	44–73 ^a
β-Tocotrienol	44–73 ^a
γ-Tocotrienol	262–437 ^a
δ-Tocotrienol	70–117 ^a
Total tocotrienols	1000–1200 ^a
Phytosterols	
Phospholipids	326–527 ^b
Squalene	5–130 ^b
Ubiquinones	200–500 ^b
Aliphatic alcohols	10–80 ^b
Triterpene alcohols	100–200 ^b
Methyl sterols	40–80 ^b
Aliphatic hydrocarbons	40–80 ^b
	50 ^b

^a O'Brien (2010).^b Zou et al. (2012).

transitions in the understanding of the nutritional and physiological effects of palm oil, its fatty acids and minor components. There is evidence that a balance between linoleic and palmitic acids may be required to maximize HDL levels. Substitution of palmitic acid from CPO or palm olein for the lauric acid and myristic acid combination from PKO or coconut oil resulted in a decrease in plasma and LDL cholesterol (Ng, Low, Kong, & Cho, 2012; O'Keeffe & St-Onge, 2013; Sambanthamurthi et al., 2000; Sundram et al., 2003). In contrast, the study conducted by Tholstrup, Hjerpsted, and Raff (2011) did not support the previous findings by Mensink, Zock, Kester, and Katan (2003) and Sundram et al. (2003), that palm olein is neutral to total plasma cholesterol and LDL cholesterol in healthy individuals with normal plasma cholesterol concentrations. Tholstrup et al. (2011) reported that compared to olive oil, palm olein and lard increased the total cholesterol ($P < 0.0001$). However, palm olein resulted in a lower plasma TAG concentration than olive oil ($P < 0.01$). The study concluded that there was no difference in the effects observed in plasma HDL-cholesterol, high-sensitivity C-reactive protein, plasminogen activator-1 (plasma proteins that respond to tissue inflammation and breakdown of blood clots), insulin, and glucose concentrations.

3.3. Micronutrients characterization

Palm oil contains minor components that demonstrate major nutritional and health benefits. The micronutrients are listed in Table 5. These micronutrients include carotenoids, tocopherols, tocotrienols, sterols, phospholipids, glycerolipids and squalene (O'Brien, 2010). The carotenoids, tocopherols and tocotrienols maintain the stability and quality of palm oil and also act as biological antioxidants (Wu & Ng, 2007). The tocopherols and tocotrienols act as anti-cancer, anti-inflammatory agents (Wu, Liu, & Ng, 2008), control atherosclerosis, and decrease cholesterol (Das, Nesaretnam, & Das, 2007). The growing interest in the bioactivities of these micronutrients has led to the development of functional foods or nutraceuticals incorporated with phytosterols, tocopherols, and tocotrienols (Zou, Jiang, Yang, Hu, & Xu, 2012).

Carotenoids are responsible for the diversity of color in nature. Alpha-carotene, β-carotene, and cryptoxanthin have demonstrated provitamin A activity. Beta-carotene is the most potent provitamin A carotenoid. Vitamin A is necessary for vision, growth, cellular differentiation and other physiological functions (Hendler & Rorvik, 2008). CPO contains 500–700 ppm of carotenoids and is thus the natural richest source of carotenoids. CPO contains 33% α-carotene, 65% β-carotene and 2% other carotenoids such as γ-carotene and lycopene (Ng et al., 2012). The carotenoids are responsible for the rich orange-red color of CPO. They act as antioxidants by trapping free radicals, neutralize thiyl radicals, chelate peroxy radicals and quench singlet oxygen in lipids. Stated simply, carotenoids protect the oil against oxidation by themselves being first oxidized before the oxidative attack on the triacylglycerols (Edem, 2002; Gunstone, 2011; Hendler & Rorvik, 2008). In 1992, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) accepted and included palm oil carotenoids as a permissible food colorant (Zou et al., 2012). CPO has been proposed as an alternative treatment for vitamin A

a genetic pool for plant breeders to develop new palms with the desired specifications such as high oleic acid palms.

Nutrition studies have not only demonstrated the adequacy of palm oil and its products, but have also led to

deficiency. The digestibility of α - and β -carotene found in CPO is high and this enhances their bioavailability (Benadé, 2003; Edem, Eka, & Umoh, 2002). Rice and Burns (2010) reviewed a series of key intervention studies designed to investigate the impact of using red palm oil to improve the status of vitamin A. The review's focus was related to the use of palm oil in dietary supplementation and food fortification studies. The conclusion stated that red palm oil increased dietary intake of provitamin A carotenoids especially β -carotenes which are more abundant and better converted than α -carotenes. Palm oil is highly effective in improving vitamin A status amongst populations at risk of vitamin A deficiency.

Tocopherols and tocotrienols (termed tocochromanols) are usually called vitamin E. They are fat soluble. They have a chromanol head, formed by phenolic and heterocyclic rings, and a phytyl tail. The number and position of methyl substitutions on the chromanol nucleus give rise to the subfamily of α -, β -, γ -, and δ -tocopherols/tocotrienols. Alpha tocopherol is the most abundant. The difference in the structure of tocopherols and tocotrienols is only in the phytyl tail. The tocopherols have a saturated tail, while the tocotrienols have an unsaturated chain with three isolated double bonds (Rossi, Alamprese, & Ratti, 2007; Zou et al., 2012). The tocopherols and tocotrienols are present at different concentrations depending on the type of vegetable oil and its origin (Gunstone, 2011). Palm oil is one of the richest sources of vitamin E in nature. The vitamin E in palm oil is unique since it is composed of both tocopherols and tocotrienols. CPO contains 600–1200 ppm vitamin E. Tocopherols account for 18–22% while tocotrienols account for 78–82%. Amongst the tocotrienols, the major ones are γ -tocotrienol, α -tocotrienol and δ -tocotrienol (O'Brien, 2010; Ping & May, 2000; Zou et al., 2012). Some vitamins E in CPO are lost during processing and refining. During fractionation, vitamin E tends to partition preferentially into the olein fraction (Obahiagbon, 2012; Sambanthamurthi et al., 2000; Sundram et al., 2003). Recent findings showed that palm oil's tocotrienols significantly diminish the synthesis of pro-collagen 1 and 3; and inhibit the transforming growth factor- β 1. These are responsible for the type of inflammatory bowel disease known as Crohn syndrome (Luna, Masamunt, Llach, Delgado, & Sans, 2011). The stability of the different tocopherols and tocotrienols present in the refined vegetable oils basically depend on the fatty acid composition of the oil, and the type of tocopherol and tocotrienol homologs present. The homolog, γ -tocotrienol in palm super olein proved to be the least stable during the deep-fat frying, thus preserving the other homologs (Rossi et al., 2007). As antioxidants, tocopherols and tocotrienols act as free radical quenchers which contribute to the stability of palm oil. Tocopherols can interrupt lipid oxidation by inhibiting peroxide formation in the chain propagation step, or the decomposition process by inhibiting aldehyde formation. Alpha tocopherol is reported to be highly reactive towards singlet oxygen and protects the oil against photo-oxidation (Sundram et al., 2003). The tocotrienols and the isometric position of its fatty acids are credited as being responsible for palm oil's nutritional benefits (O'Brien, 2010). Carotenoids, along with vitamin E, protect the oil from thermal oxidation. During thermal oxidation carotene radicals are formed which are converted back to active carotene

in the presence of tocotrienols. Schroeder et al. (2006) reported that this synergistic relationship decreased the oxidation of oil during frying of potato slices at 163 °C.

Other minor components of palm oil such as the sterols, higher aliphatic alcohols and hydrocarbons are found in the unsaponifiable fraction. Similar to all other edible oils of vegetable origin, the cholesterol content of palm oil is negligible. Refining decreases the phytosterols, ketones, wax and methyl esters present (Edem, 2002; Sambanthamurthi et al., 2000). Ping and May (2000) reported that, generally the minor components act as antioxidants, boost energy, enhance the immune system and provide benefits in the prevention and treatment of coronary heart diseases (CHD). Palm oil also contains low levels (<100 mg/L) of phenolic compounds. The phenolic compounds are responsible for the initial darkening of palm oil during frying (Berger, 2005; Sundram et al., 2003). Like all vegetable oils, a mixture of sterols is found in CPO, palm olein and their refined products. The sterols found in palm oil include β -sitosterol, campesterol, stigmaterol and avenasterols. Amongst them, avenasterols exhibit antioxidant activity (Berger, 2005; Gunstone, 2011). The sterols of plant origin are referred to as phytosterols. Phytosterols are susceptible to oxidative degradation during food processing operations such as frying. During frying, phytosterols degradation occurs due to auto-oxidation. The products of this degradation are termed phytosterols oxidation products (POP). The POP can be found in both frying oil and the fried products (Dutta, Przybylski, Eskin, & Appelqvist, 2007). Tabee, Jägerstad, and Dutta (2009) reported that the POP found in palm olein used in frying French fries at 180 °C for 5 h increased from 1.9 μ g/g to 5.3 μ g/g in the final batch. The degradation of phytosterols depends on the type of oil and polyunsaturated fatty acids present. Phytosterols appear to degrade faster in oils with high content of linoleic and linolenic acids. The rate of POP formation is also influenced by the type of sterol and the tocopherols content of the oil (Przybylski, Zambiasi, & Li, 1999).

Generally there is no clear evidence of a negative effect of palmitic acid on health (Fattore & Fanelli, 2013). CPO is a complex alimentary medium, in which palmitic acid is just one of its many components. The presence of oleic acid and many antioxidant compounds in palm oil provide some form of nutritional balance. While POP are absorbed and found in human serum, they do not directly affect the absorption of cholesterol (O'Callaghan, McCarthy, & O'Brien, 2014).

4. Use in frying

Frying is cooking food in fat or oil. It includes deep-frying, stir-frying, pan-frying and sautéing. In the 1980s, there were campaigns to convince the public that food products containing saturated tropical oils contributed to increased risk of coronary heart disease (McNamara, 2010). These tropical oils include coconut oil (CNO), palm kernel oil (PKO) and crude palm oil (CPO). Saturated fatty acids such as lauric acid and myristic acid (from CNO and PKO) have demonstrated cholesterol-raising effect (Wattanapenpaiboon & Wahlqvist, 2003). This has amplified uneasiness over the health consequences of the consumption of palm oil since it contains large amount of palmitic acid. Decker (1996), Innis (2011), and

Karupaiah and Sundram (2007) strongly reasoned that fatty acid stereospecific locations must be given important consideration in the design and interpretation of lipid nutrition studies.

Since then research into the utilization of palm oil and its fractions have intensified. The use of palm oil and its fractions in food processes is illustrated on the chart shown in Fig. 3. It ranges from use in domestic cooking and frying to large scale production. Certain characteristics of palm oil such as a high solid fat content (requiring no hydrogenation), high oxidative stability (long shelf life), high and low melting TAGs (wide plastic range), constant supply, competitive price, slow crystallization properties, structural hardness, and a tendency for recrystallization permit the use of palm oil in these food applications (Barriuso et al., 2013; Edem, 2002).

Deep-fat frying is one of the most popular methods for the preparation of food. It is an easy, fast, and a relatively cheap cooking method that results in palatable foods with wonderful flavors and aromas. Frying temperatures range between 150 °C and 190 °C. Most deep-fat frying operations are done at 180 °C. During frying, heat and mass transfer processes occur between the oil and the food. The outcome is a cooked, dried and crispy product (Blumenthal & Stier, 1991; Choe & Min, 2007; Krokida et al., 2000). Fried food quality is a function of the oil quality. Frying enhances color, flavor and texture of the fried food. Lesser nutrients losses occur during frying than during cooking in water and stewing. Water soluble vitamins, proteins and carbohydrates are also better retained. Frying, like cooking in water, improves digestibility and bioavailability of some nutrients in the digestive tract (Bognar, 1998; Zhang, Wang, Wang, & Zhang, 2014). Frying increases the amount of fat in the fried product and can lead to loss of heat labile and oxidation susceptible vitamins (Boskou, 2011; Pokorny, Panek, & Trojakova, 2001).

During frying a number of chemical reactions such as oxidation, polymerization, and hydrolysis of the fatty acids occur. These reactions change the oil from a medium that is almost pure triacylglycerol when fresh to one that contains literally thousands of different degradation compounds. This

could compromise the texture, taste, flavor and the overall perception of the product. In addition, potential risk to human health and nutrition may arise (Naghshineh & Mirhosseini, 2010; Stier, 2013). Therefore, in choosing frying oil, the oxidative and thermal stability are very important indices, since the frying oil becomes a significant part of the food. The fatty acid composition of the oil naturally present in the food is changed towards the fatty acid composition of the oil used for frying (Matthaus, 2007). For instance, frying with olive oil resulted in a high amount of oleic acid in the fried product, whereas saturated and monounsaturated fatty acids predominated in products fried in palm olein. Oils with higher amounts of PUFAs are not stable to oxidation and the products fried using such oils have shorter shelf stability. PUFA oils quickly break down at frying temperatures to form gums (Boskou, 2011; Matthaus, 2007).

Frying medium can be all-vegetable oil, all-animal fat, a blend of animal fats and vegetable oils or a blend of different vegetable oils. The important characteristics of frying lipids are high oxidative stability, high smoke point, low foaming, low melting point, bland flavor and good nutritional value. FFA <0.1% indicates that the oil is properly refined. The peroxide value (PV) is a measure of initial oxidation products; if PV <1.0 meq O₂/kg, the oil is fresh. A smoke point >200 °C is recommended so that the oil does not smoke when first used. Moisture content <0.1% indicates the frying oil is pure fat, and no spattering will occur when first used. Another test commonly quoted in the technical trade is the Rancimat stability, which gives an indication of the stability of a fat. To avoid quick polymerization, regulations in most developed countries limit the amount of linolenic acid (C18:2) to ≤2% (Boskou, 2011; Kochhar, 2001; Stier, 2013). CPO and palm olein contain no *trans* fatty acids. They contain moderate amount of linoleic acid, and little or no linolenic acid. They have high levels of antioxidants (tocotrienols, tocopherols and β-carotene). These excellent properties make CPO and palm olein ideal for domestic and industrial frying (Edem, 2002; Lin, 2011; Sue, 2009).

Palm oil has largely replaced beef tallow and lard in large scale industrial frying. Palm oil and palm olein are mostly used to fry foods like French fries, fried chicken, instant noodles, snack foods (Fan & Eskin, 2012) and chicken fillets (Chen et al., 2014). A large amount of palm oil is also used for frying in fast food restaurants (Berger, 2005). Matthaus (2007) reported that palm olein was comparable with high oleic vegetable oils and hydrogenated sunflower and cottonseed oils in terms of oxidative stability during frying. Palm oil is resistant to oxidation, polymerization and foaming. Palm oil does not produce any gummy or sticky residues in the fryer. Kochhar (2001) reported that palm oil's good performance and high oxidative stability is making it the oil of choice for the major snack food manufacturers in many European Union (EU) countries. The most popular commercial frying oil is palm olein which has a lower melting point (22–24 °C) than CPO (32–36 °C), resulting in no waxy or greasy mouth-feel of the fried products (Lin, 2011). Xu, Tran, Palmer, White, and Salisbury (1999) reported that palm olein had comparable frying performance as high-oleic, low linolenic canola oil. The useful life of palm oil as a frying medium is reported to be 12 days of continuous frying. The frying oil management may

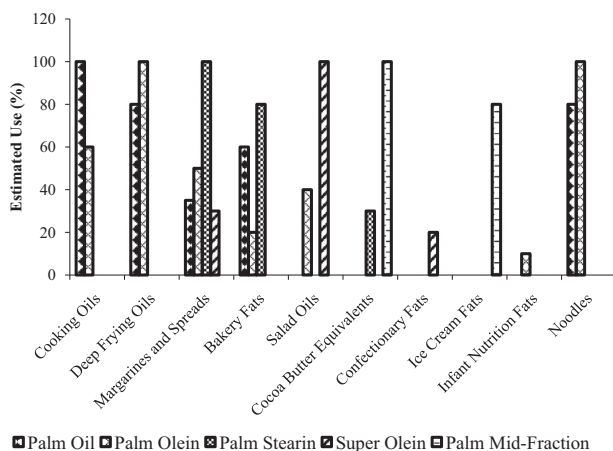


Fig. 3 – Specific food applications of palm oil and its fractions.

involve filtration and replenishment of oil with fresh oil samples (Ismail, 2005).

Oil and nutrient diffusion in the fried product depends on the shape, nature, texture and microstructure of the food. It also depends on the viscosity of the oil, the frying temperature and time (Boskou, 2011). The use of palm oil in frying is based not only on the frying stability, but also on the assumption that the tocopherols, tocotrienols, the carotenoids and phenolic components will migrate into the fried products. The major mechanisms of the diffusion of these micronutrients together with the frying oil are molecular mechanism (Aguilera, 2005); capillary forces (Moreira & Barrufet, 1998; Yamsaengsung & Moreira, 2002) and over pressure across the food matrix also referred to as vacuum effect after removing food from the fryer (Vitrac, Dufour, Trystram, & Raoult-Wack, 2002; Ziaifar, Achir, Courtois, Trezzani, & Trystram, 2008). The amounts of micronutrients in fried products can be estimated from their respective concentrations in the frying oil. The type of oil, the quality, and the frying procedure appear to have an impact on the diffusion and distribution of these nutrients in the fried product. The amounts of the minor constituents tend to decrease during frying thus affecting their concentration in food products (Chiou, Kalogeropoulos, Boskou, & Salta, 2012). Not much has been published to detail the presence of these micronutrients in fried foods. Table 6 shows that while many types of foods have been fried and studied only French fries have been studied to a limited extent concerning its enrichment with micronutrients from the oil. The evaluation and characterization of the constituents of the oil absorbed by different food products still require closer attention in order to promote the manufacture of micronutrients enriched fried products.

5. Blending

In the frying industry, the trend is to modify the vegetable oil in order to improve the nutritional quality, functional properties, oxidation stability and technical performance of the frying oil. Blending two or more oils with different characteristics, such as fatty acid chain length and/or patterns of unsaturation, is another option to making new specific frying oils (De Leonardis & Macciola, 2012; O'Brien, 2010; Tiwari, Tiwari & Toliwal, 2014).

In blending, the composite oils share advantages and disadvantages depending on the blend ratio. It is important that the blend complies with all the food laws and guidelines as well as meet consumers' expectations. The objective of blending can be commercial, technical, functional, nutritional or their interactions depending on the intended application. Blending is widely accepted because it does not increase processing cost (Chu & Kung, 1998; Waghray & Gulla, 2011). Blending of polyunsaturated oils with highly saturated oils reduces the content of linoleic and linolenic acids to the desirable level where the effect is similar to partial hydrogenation without worrying about the formation of trans fatty acid isomers (Hoffmann, Swiderski, Zalewski, & Berger, 2002; Naghshineh & Mirhosseini, 2010; Tiwari et al., 2014). It may be necessary to interesterify oil blends. Interestification is a procedure for rearranging the fatty acids in oil or in

Table 6 – The distribution of micronutrients in products fried in palm oil or palm olein.

Food	Frying conditions		Micronutrients					References
	Temperature (°C)	Time (min)	Total polyphenol (CAE mg/100 g)	Phytosterol (µg/100 g)	Total carotene (µg/100 g)	Total tocopherol (µg/100 g)	Total tocotrienol (µg/100 g)	
Frozen par fried potato	180	5	-	-	1388	-	-	Andreu-Sevilla et al. (2009)
French fries	175±5	6	8.2	-	-	-	-	Chiou et al. (2007)
French fries	175±5	6	-	-	-	1200	-	Chiou, Kalogeropoulos, Salta, Efstathiou, and Andrikopoulos (2009)
French fries	175±5	6	-	8200-20,800	-	-	-	Salta, Kalogeropoulos, Karavanou, and Andrikopoulos (2008)

CAE = caffeic acid equivalents.

a blend of oils so that triacylglycerol composition is changed. The fatty acid composition of the single oil or the blend remains unchanged and do not interact with triacylglycerols as they are of similar chemical composition (Benjumea, Agudelo, & Agudelo, 2008; Christie & Han, 2010).

The oxidation stability of a blend highly depends on those of the individual oils in the mix (Isbell, Abbott, & Carlson, 1999; Tiwari et al., 2014). The oxidative stability of palm oil in a blend is principally due to its high saturation and heavy presence of natural antioxidants, especially γ -tocotrienol (Bansal, Zhou, Barlow, Lo, & Neo, 2010; De Leonardis & Macciola, 2012; De Marco et al., 2007). Different researchers have evaluated the frying characteristics of blends of other vegetable oils and palm oil/palm olein (Del Carmen Flores-Álvarez, Molina-Hernández, Hernández-Raya, & Sosa-Morales 2012; Kupongsak & Kansuwan, 2012; Naghshineh & Mirhosseini, 2010; Tiwari et al., 2014). Blending palm oil with rice bran oil significantly lowered serum lipids in rats after 8 weeks of feeding trial (Reena & Lokesh, 2012). De Leonardis and Macciola (2012) reported that the fatty acid composition of oils and blends appeared to be the most decisive factor influencing oxidation stability. The saturated/unsaturated fatty acid ratio near to 1 offers optimally stable condition. The American Heart Association/WHO guideline for smart blend ratio is 1:1:1 for SFA, MUFA and PUFA vegetable oils. Some important findings in literature concerning blends of

palm oil or palm olein are summarized in Table 7. Hayes and Khosla (2007) reported that palm oil (or palm olein) is the oil of choice for blending with unsaturated oils to provide specific functional characteristics without compromising health. This is because partially hydrogenated fats contain *trans* fatty acids which have demonstrated adverse health effects (Chen et al., 2014; Mozaffarian, Aro, & Willet, 2009). Blending tailors and improves frying properties of oil by fine tuning the fatty acid composition and antioxidant balancing. It improves the fried product quality, improves appearance and enhances the shelf life of the product. Blending also helps moderate the retail prices of oil for the consumers benefit.

6. Conclusion

Palm oil has nearly equal amounts of saturated and unsaturated fatty acids. Palmitic acid is the major saturated fatty acid while oleic acid is the monounsaturated fatty acid. The oil is semi-solid at room temperature; it does not require hydrogenation. With about 500–700 ppm of carotenoids, palm oil is nature's richest source of β -carotene and lycopene. It is also very rich in vitamin E, especially tocotrienols and tocopherols. The carotenoids and the vitamins E act synergistically as powerful natural antioxidants. They confer

Table 7 – Summary of effects of blending palm oil/palm olein and other vegetable oils.

Oil blends	Blend ratio, % (palm oil: other oil)	Effect	Reference
Palm oil:sunflower oil	80:20	Palm olein with much higher IV	Nor Aini, Hasmadi, Mamot, and Radzuan (2005)
Palm olein:olive oil	60:40	40% Blends reduced olein's cloud point	Naghshineh et al. (2009)
	75:25	Oil remained liquid at ambient temperature.	
	50:50	Increased oxidative stability	
Palm olein:canola oil	50:50	Better PV after repeated frying at 180 °C; French fries had reduced fat content than olein alone	Enriquez-Fernandez, Yanez, and Sosa-Morales (2011)
Palm olein: canola oil	50:50	Stable against oxidation; depressed melting point	Mobin Siddique et al. (2010)
Palm oil:extra virgin Olive oil	88:20	Induction time and oxidative stability similar to pure palm oil at 120, 130 and 140 °C	De Leonardis and Macciola (2012)
Palm olein:sunflower oil	50:50	Exhibited very high radical scavenging activity	Ramadan, Amer, and Sulieman (2006)
Palm olein:peanut oil	90:10 to 60:40	Increasing peanut imparted a pleasant nutty flavor; significant changes in percentage of C16:0 and C18:2	Myat, Abdulkarim, Mohd Ghazali, and Karim (2009)
Palm oil:sunflower oil	65:35	Decreased rate of evolution of FFA and polar compounds during 8 h of discontinuous frying; reduced degradation rate of tocopherols and tocotrienols	De Marco et al. (2007)
Palm olein:canola oil	75:25	Frying stability of canola oil significantly improved by the blending	Farhoosh, Kenari, and Poorazrang (2009)
Palm olein:olive oil: corn oil	75:15:10	Frying performance of ternary blend better than binary blends	Farhoosh et al. (2009)
Palm oil:sesame oil	52:48	Resulted in ideal fatty acid composition of 1:1:1 (SUFA:MUFA:PUFA) stable to oxidative deterioration enhanced nutritional qualities	Tiwari et al. (2014)

oxidative stability to palm oil in most food applications especially during frying. CPO can be fractionated to a liquid palm olein and a solid palm stearin. This further diversifies the oil's usefulness. Worldwide, 90% of palm oil is used for edible purposes while 10% is used in the soap and oleo-chemical industries. Palm oil is widely used as frying oil because of its high smoke point (230 °C) and a stronger resistance to thermoxidation than most other vegetable oils. Blending palm oil with more unsaturated or monounsaturated oils is an option adopted to improve and enhance the commercial, functional, nutritional and technical attributes of the oil. Blending minimizes the changes caused by hydrolysis, oxidation, and polymerization during high thermal stress. Blending is a desirable alternative to the negative effects associated with hydrogenation and high cost associated with interesterification.

It is recommended that more attention be given to studying the retention and migration of the micronutrients into the fried products with a view to optimizing production of healthier fried products. The distribution of the absorbed oil within the food matrix as well as interaction between the native food nutrients and the frying oil should be investigated. The health implications of using composite oils should be studied further. The kinetics of degradation of CPO and blends as frying medium also needs to be evaluated.

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