# Physico-chemical properties, fatty acid profile and nutrition in palm oil

Mohammadreza Koushki, Masoomeh Nahidi*, Fatemeh Cheraghali

Department of Food Technology Research, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran

*Corresponding Author: email address: p.nahidi@yahoo.com (M.Nahidi)

## ABSTRACT

The rapid expansion in world production of palm oil over the last three decades has attracted the attention of the oils and fats industry. Oil palm gives the highest yield of oil per unit of any crop. Palm oil is the major oil produced, with annual world production in excess of 50 million tonnes. Throughout the world, 90% of palm oil is used for edible purposes (e.g., margarine, deep fat frying, shortening, ice creams, and cocoa butter substitutes in chocolate); the remaining 10% is used for soap and oleo chemical manufacturing (fatty acids, methyl esters, fatty nitrogenous derivatives, surfactants and detergents). Two distinct oils are produced by oil palms (palm kernel oil and palm oil), both of which are important in world trade. Palm oil contains 50% saturated fatty acids. The saturated fatty acid to unsaturated fatty acid ratio of palm oil is close to unity and it contains a high amount of the antioxidants, β-carotene, and vitamin E. Palm oil contains a high proportion of palmitic acid as well as considerable quantities of oleic and linoleic acids. The physicochemical properties, fatty acid profile and nutrition in palm oils are reviewed.

**Keywords**: Palm oil; Palm Kernel oil; Physicochemical properties; Fatty acid profile; Nutrition.

## INTRODUCTION

Palm oil is an important and versatile raw material for both food and non-food industries [1]. Recently, palm oil has become the second most consumed oil all over the world with a competitive price compared to other edible oils [2]. The Oil palm is as old as creation. Every part of the tree is useful economically and for domestic purposes [2, 3]. The oil palm is grown commercially in Africa, South America, Southeast Asia, and the South Pacific, and on a small scale in other tropical areas. Until recent centuries the palm has been confined to West and Central Africa where it existed in a wild, semi wild, and cultivated state. In Africa it remained a domestic plant, supplying a need for oil and vitamin A in the diet, and it was not until the end of the eighteenth and the beginning of the nineteenth centuries that oil palm cultivation expanded to the Southeast Asian regions and strengthened the entry of palm oil into the world oils and fats trade [4].

Palm oil is one of the 17 major oils and fats produced and traded in the world today. Within the span of four decades, palm oil has emerged as the fastest growing oil in the world. In fact, palm oil is projected to be the world's largest oil produced, although it is currently occupying second position after soybean oil [5]. Most palm oil is currently produced in South East Asia, even though the oil palm is originally an African crop, which was introduced to South East Asia in the 19th century. The two largest producers are Malaysia and Indonesia, who together account for roughly 85% of the world palm oil production [6, 7]. The success of the Malaysian palm oil industry is the result of the ideal climatic conditions, efficient milling and refining technologies and facilities, research and development, and efficient and adequate management skills. Practically all palm oil mills generate their own heat and power through the co-generation system [6, 8].

Palm oil, obtained from a tropical plant, *Elaeis guineensis.* The genus Elaeis comprises two species, namely E. guineensis and E. oleifera. Palm oil is a lipid extracted from the fleshy orange-red mesocarp of the fruits of the oil palm tree. The oil palm tree has an unbranched stem and belongs to the Palmae family. The tree, which can grow to a height of 20 to 30 meters, has an economic life span of 25 to 30 years. The female bunch produced can weigh as much as 30–40 kg and contain up to 2000 fruitiest which are black in color when young, turning to orange-red when ripe[9,11]. Germination takes around 3 months, after which the seedlings are planted in plastic bags and transplanted into a field at an age of around 1 year and produce their first bunches of fruit after less than 2 years[6, 12]. The number of leaves in an oil palm plant increase from 30 to 40 in a year at the age of 5 to 6 years. After that, the generation of leaves decreases to about 20 to 25 per year[6,13].

Malaysia has been the leading exporter of palm oil, reflecting the country's large production and refining capacities, its small domestic market for palm oil[1,14]. In much of Asia, palm oil is popular because of its relatively low price vis-à-vis soybean oil, its main competitor, reinforced by the modest freight costs from South East Asian suppliers. Also, the temperatures in the tropical/sub-tropical regions are warm enough to allow refined bleached deodorized(RBD) palm olein to be used as household oil, without fear of clouding [15]. Today, palm oil is the most widely used vegetable oil in the world. As shown in Figure 1 palm and palm kernel oils accounted for 35% percent of total vegetable oil production, Soybeans were the next largest source of vegetable oil27%, followed by rapeseed (the basis of canola oil)15% in 2011. In addition Palm oil was not always the most widely used vegetable oil in the world. In 1961, only 1.5 million tonnes was produced, compared to 3 million tonnes of soybean oil. In 2006, however, palm oil production surpassed soybean oil production for the first time, and by 2011, world production of palm oil amounted to 48.6 million tonnes, compared to 41.6 million tonnes of soybean oil.

Today, Indonesia is the world's largest producer of palm oil, with Malaysia coming in at a close second (Table 1) [16].

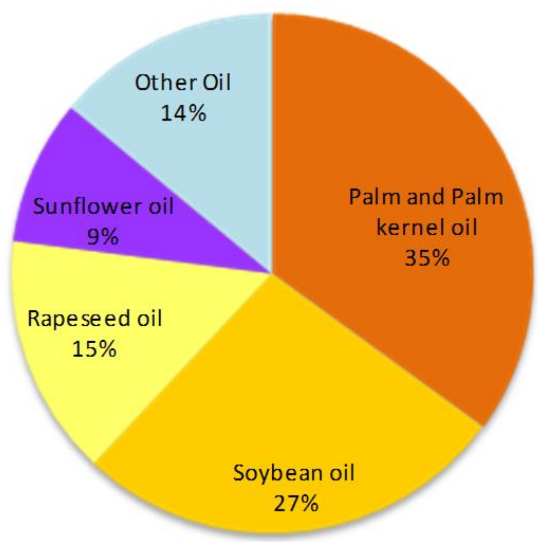


**Figure1.** Global vegetable oil production (2011)

**Table1**.World supply and distribution (Thousand Metric Tons)

| Production | 2010/11 | 2010/12 | 2010/13 | 2010/14 | 2010/15 | 2010/16 |
|---|---|---|---|---|---|---|
| **Indonesia** | 23,600 | 26,200 | 28,500 | 30,500 | 33,000 | 33,000 |
| **Malaysia** | 18,211 | 18,202 | 19,321 | 20,161 | 21,250 | 21,250 |
| **Thailand** | 1,832 | 1,892 | 2,135 | 2,150 | 22,250 | 2,250 |
| **Colombia** | 753 | 945 | 1,140 | 1,042 | 1,070 | 1,070 |
| **Nigeria** | 850 | 850 | 910 | 930 | 930 | 930 |
| **Other** | 3,590 | 4,022 | 4,138 | 4,276 | 4,293 | 4,293 |

Palm oil has the color of a rich, deep red which is said to be derived from its rich carotenoid contents, which are known as pigments often found in plants and animals. Palm oil is a viscous semi-solid and a solid fat in temperate climate because the major components of its glycerides are the saturated fatty acid palmitic [17]. The major and minor components of the palm oil play numerous health functions in humans. Some metabolites which play notable roles in the biosynthesis of triglycerides and products of lipolytic activities have been detected in the palm oil [3].

Palm oil contains a high concentration of natural carotenoids of 500-700 ppm [18-23]. The main carotenes present in crude palm oil are β-carotene (56%) and α-carotene (35%). Both β-carotene and α-carotene are provitamin A. Compared with other sources of natural carotenoids , palm oil has 15 times more retinol equivalents than carrots and

300 times more than tomatoes [18]. Studies have also strongly associated beta carotene with the prevention of certain types of cancer, such as oral, pharyngeal, lung and stomach cancers[18,24-26]. Palm oil has wide applications for the production of high value products for pharmaceutical, food and fuel industries[27]**.**
Therefore present article reviewed the physic-chemical properties, fatty acid profile and nutrition in palm oil.

## Kinds of Palm Oil

Palm oil is unique among vegetable oils because of its high saturated acid content with a significant amount (10-16%) of saturated acids at the 2-position of its triglycerides. Palm oil also contains appreciable amounts of diglycerides (5-8%) and free fatty acids, which can have a substantial effect on its physical properties. Under normal ambient conditions (20-30° C), palm oil appears as heterogeneous slurry of crystals in liquid oil. The separation of these phases is the basis of the large-scale fractionation processes applied to palm oil. These fractionation processes are relatively easy to operate, because the phases are more distinct than in other fats. A most useful and comprehensive study of the phase behavior of palm oil has been reported [28, 29]. It has a high oxidative stability and results in high-quality and tasty foods. The suitability of palm oil and its products for frying was widely demonstrated in many investigations, and the paper shows some examples for the comparison of palm oil with other commonly used oils. The oil is a solid fat in temperate climates, because it consists of 32–47% saturated fatty acids, with palmitic acid as main saturated fatty acid [30-32]. Palm oil obtained exclusively from the red fruits, which is lower in palmitic acid but higher in oleic acid, would be more suitable for processing into vegetable oil, while the oil from the yellow fruits could be more useful in the production of soap and detergent [33]. Palm is unique in that it produces two types of oil. Palm oil is edible oil referred to by the FAO/WHO Codex Alimentarius as being derived from the fleshy mesocarp of the oil palm fruit and Palm kernel oil is derived from the kernel of the fruit of the oil palm [34].

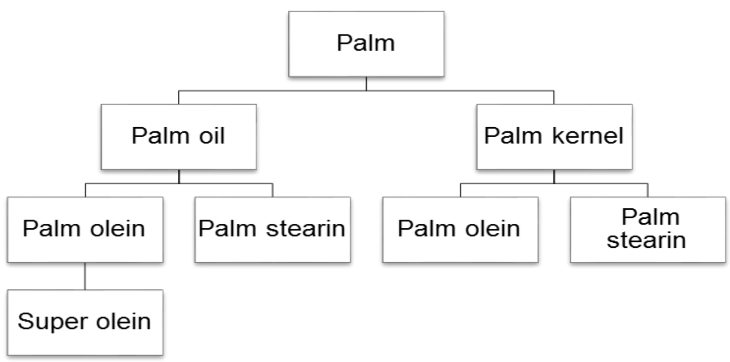


**Figure 2.** Classification of palm oil [34]

In the unprocessed form palm oil is reddish brown in color, and it has a semisolid consistency at ambient temperature. Readers should not confuse palm oil with palm kernel oil, which is another product obtained from the kernel of the oil palm fruit that has wide application in the oleo chemical industry while palm oil is derived from the mesocarp or fruit flesh. Palm oil applications in food are shortening, margarine, deep frying fat, and specialty fats. Palm kernel fats or fractions or derived products are used for confectionery products as partial cocoa butter replacers and as ice cream fats and coating [4, 11, 29].

With increasing interest in cocoa butter replacers, many refiners are attempting to produce a satisfactory middle melting fraction from palm oil which will be more or less compatible with cocoa butter[23].

Crude Palm Oil (CPO) and Palm Kernel Oil (PKO), two main oil, yields from palm oil fruit are extracted from the mesocarp [28, 35, 36]. These oils have different characteristic and properties [28]. The properties of CPO make it suitable for food products (e.g. margarine, cooking oil), while PKO is used for nonfood products (e.g. cosmetics). In food products, product quality is crucial, compare with non food products [37] .The unripe fruits contain very little oil but the mesocarp of ripe fruits has an oil content of 70–75% of its total weight [38]. The main products derived from palm kernel are palm kernel oil, palm kernel stearin whereas the by-products are palm kernel meal and palm kernel fatty acid distillate. The major composition of the kernel is oil (49%), followed by carbohydrate (26.1%), protein and crude fiber (8% each) [39].

Palm oil may be fractionated into two major fractions: liquid oil (65– 70%) palm olein (m.p. 18–20 °C) and a solid fraction (30–35%) stearin (m.p. 48–50 ◦C).Palm olein is the fractions obtained from refining, bleaching and deodorization of palm oil. The fractionation process consists of crystallization of that portion of the glycerides that solidify at the temperature of operation followed by their separation from the remaining liquid portion. The latter fraction is generally referred to as olein, and the higher melting portion is called stearin[40]. This fractionation brings about an increase in monounsaturated oleic acid with the concomitant reduction of palmitic acid, the major saturated fatty acid. Palm oil contains a high proportion of palmitic acid as well as considerable quantities of oleic and linoleic acids. Palm olein is also suitable as dietary fat and in infant formulation. The suitability of palm oil and palm olein for frying of different foods is widely described in many publications [8, 28, 30]. It is also possible to modify both palm oil and palm olein by hydrogenation to obtain hard fats with different properties. Because of the high palmitic acid content of palm oil and its various products, it has interesting polymorphic properties, which may be used to advantage in blending with different oils and fats used in the production of margarines and shortenings [41]. Red palm oil (RPO) contains 50% saturated, 40% monounsaturated and 10% polyunsaturated fatty acids. RPO and refined palm olein (REFPO) have good oxidative stability due to the presence of natural antioxidants (tocopherol and tocotrienols) and the absence of linolenic acid [17, 42].

Two other types of products are produced by specific fractionation. The first range of products is that of super olein of lower cloud point. The second type is that of palm mid-fractions as cocoa butter replacers. More sophisticated processing can provide other fractions such as mid-fraction and the double fractionated palm olein (super olein). Palm mid-fraction, which has properties somewhere between olein and stearin, contains 60% palmitic and 40% oleic acid, and is used as a cocoa-butter equivalent. When the target is to produce an olein for temperate and cool climates, the required specifications usually are a cloud point below 5 °C and a minimum iodine value of 60. Such oleins also are blended with a more unsaturated oil such as soybean oil to improve the low temperature stability[43].Food manufacturers choose palm oil because it has a distinct quality, requires little or no hydrogenation, and prolongs the shelf life of different products[44,45].

Meanwhile Palm shell as by product of the palm oil industries is abundantly available mainly in South East Asia (Malaysia, Indonesia and Thailand). For example in Malaysia, the world largest producer of palm oil, approximately 2 million tons of palm shell produced annually. Currently, most of these agricultural wastes burned to generate steam. Many previous studies have been done on the utilization of palm shell as raw material of AC production and it was reported that due to its high density, high carbon contents and low ash, this material can be used for the production of good quality AC. Also, in comparison with similar byproduct precursors for AC preparation like coconut shell at same preparation conditions, palm shell base AC have shown higher adsorption capacity and better micro pore development[46,47].

Palm oil is known to support the growth of fungi and bacteria especially when it contains moisture. Their lipolytic enzymes are so active that even under unfavorable conditions palm oil is seldom produced with a free fatty acid content (FFA) of less than 2% and under favorable conditions of processing, the free fatty acid content of this oil reaches 20%and higher. When the fruit is bruised, lipolytic action occurs and a near maximum FFA (8-10%) is reached within 40 minutes. The FFA of unbruised fruits may increase only 0.2% or less in the course of 4 days [47].

## Kinds of Fatty acids

Palm oil quality and price is dependent on the free fatty acids (FFA) content in palm oil. High content of free fatty acids in palm oil affect the quality of palm oil and leads to various health and environmental issues. while the fatty acid composition of palm oil may vary with the country of origin, oils from the same country are reasonably consistent, particularly where the oil production is plantation-based and maximum benefit is obtained from control of ripeness at time of harvesting, and genetic uniformity of the fruit[22].The maximum free fatty acids content set by the Palm Oil Refiners Association of Malaysia in crude palm oil is 5 % and < 0.1 % in refined bleached deodorized oil. Due to the high demand in palm oil industry market nowadays, various works has been done to improve the quality of palm oil including the determination and reduction of free fatty acids in palm oil [48]. Like all oils, Three AcylGlycerols (TAGs) are the major constituents of palm oil. Over 95% of palm oil consists of mixtures of TAGs, i.e. glycerol molecules, each esterifies with three fatty acids [49, 50]. The triglyceride (TG) composition of palm oil is normally determined by high-performance liquid chromatography (HPLC). The HPLC chromatograms indicated a good separation of most of the TG components in the oil [49, 51]. The major fatty acids in palm oil are myristic, palmitic, stearic, oleic and linoleic. Most of the fatty acids of palm oil are present as TAGs. The different placement of fatty acids and fatty acid types on the glycerol molecule produces a number of different TAGs. There is 7±10% of saturated TAGs, predominantly tripalmitin. The fully unsaturated TGs constitute 6 to 12%[49,50].The minor constituents of palm oil can be divided into two groups. The first group consists of fatty acid derivatives, such as partial glycerides Monoglycerides (MGs), Diglycerides (DGs), phosphatides, esters and sterols [50]. Phospholipids and glycolipids are the polar lipids of palm oil, with the former receiving considerable attention because of the suspected deleterious effect of phosphorus on oil quality[36,52,53]. The second group includes classes of compounds not related chemically to fatty acids. These are the hydrocarbons, aliphatic alcohols, free sterols, tocopherols, pigments and trace metals. Different isomers of MGs and DGs are found in palm oil. α-MGs are more stable than their β-isomers. As in most vegetable oils, the α,α'-DGs (or 1,3 DGs) are the predominant DGs in palm oil [50].

The major fatty acids in palm oil are myristic (14:0), palmitic (16:0), stearic (18:0), oleic (18:1) and linoleic (18:2) [50]. Palm oil contains almost equal amounts of saturated and unsaturated fatty acids. It contains negligible amounts of the hypercholesterolemia fatty acids, lauric (12:0) and (14:0). It is moderately rich in the hypocholesterolemic monounsaturated oleic acid (18:1) and has adequate amounts of linoleic acid (18:2 $\omega$ 6) [10, 54, 55]. The fatty acid chains present in the palm oil triglycerides could vary in the number of carbons present in the chain (chain length) and in structure (presence of double bonds, i.e., unsaturation) (Tables 2, 3)[4].

**Table 2.** Fatty acid composition

| | Oleins | | Stearin |
|---|---|---|---|
| **Fatty Acids** | **Range Observed** | **Mean** | **Range Observed** |
| 12:00 | 0.1 - 0.5 | 0.2 | 0.1 - 0.6 |
| 14:00 | 0.9 -1.4 | 1.0 | 1.1 - 1.9 |
| 16:00 | 37.9 -41.7 | 39.8 | 47.2 - 73.8 |
| 16:01 | 0.1 - 0.4 | 0.2 | 0.05 - 0.2 |
| 18:00 | 4.0 -4.8 | 4.4 | 4.4 - 5.6 |
| 18:01 | 40.7 - 43.9 | 42.5 | 15.6 -37.0 |
| 18:02 | 10.4 -13.4 | 11.2 | 3.2 - 9.8 |
| 18:03 | 0.1 - 0.6 | 0.4 | 0.1 - 0.6 |
| 20:00 | 0.2 - 0.5 | 0.4 | 0.1 -0.6 |
| Iodine Value (Wijs) | 56.1 -60.6 | 58.0 | 21.6 - 49.4 |

**Table 3.** Triglyceride composition by carbon number

| | Oleins | | Stearin |
|---|---|---|---|
| **Carbon Number** | **Range** | **Mean** | **Range** |
| C46 | _ | _ | 0.5 3.3 |
| C48 | 1.3 - 4.0 | 2.3 | 12.2 - 55.8 |
| C50 | 37.7 -45.4 | 42.0 | 33.6 - 49.8 |
| C52 | 43.3 - 51.3 | 45.7 | 5.1 -37.3 |
| C54 | 7.0 - 12.6 | 9.9 | Trace - 8.4 |

Palm olein, super olein and RPO share the same major fatty acids e.g. (16:0), oleic and linoleic acids. However, palm olein and super olein have more oleic and linoleic acids but less palmitic acid than does palm stearin. In fact, palm olein and super olein are more unsaturated. Because of the semisolid texture of palm oil at room temperature, hydrogenation is not necessary. Hydrogenation leads to the production of appreciable quantities of trans fatty acids that have uncertain health effects. Palm oil and its fraction contain less than 1.5% of the hypocholesterolemic lauric and myristic acids. In palm oil, 17–23% of the (16:0) is in the sn-2 position while most of the saturated myristic, and stearic acids are in the sn-1,3-configuration suggesting the reason for a low thrombotic tendency of palm oil since the usual precursors for desaturation and elongation in the four fatty acid families are essentially the fatty acids in the 2-position[10]. Palmitic acid content increased and linoleic acid content decreased linearly with the number of frying cycles [56].

For determination of the free fatty acid content of a fat/oil is the number of milligrams of KOH required to neutralize mg of FFA present in fat/oil sample. The free fatty acid contents of the palm oil types/samples were determined according to the method described [57]. The acid value is the number of mg of KOH necessary to neutralize the free acid in mg of sample. The acid value is given by T – B x 5.61/W. 0.1M KOH contains 5.6mg/ml or 5.6g/l where T=Titer value of the sample; B=Titer value of a blank. The blank was provided as a control by titrating 2.5ml of the neutral alcohol without sample. The free fatty acid (FFA) is normally determined as oleic acid where by the acid value = 2 x FFA. NaoH may be used and a generalized formula may be used (for palm oil and fractions): 25.6 x M NaoH x V/W where V= Volume of NaOH solution used in ml; W=Weight of sample [47].

**Physico-chemical properties**

The physical and chemical properties of palm oil, like other lipids, are essentially determined by the nature of the constituent fatty acids, which make up approximately 95% of the glyceride molecule[33]. Palm oil, like all oils and fats, is made up mostly of glyceridic materials with some nonglyceridic materials in small or trace quantities. It is this chemical composition that defines the chemical and physical characteristics of palm oil, which in turn will determine the suitability of the oil in various processes and applications [4].

Palm oil and hardened groundnut oil had the greatest oxidative stability at high temperature, in comparison to animal fats or highly unsaturated oils, with regard to the chemical parameters but also concerning the sensory evaluation [30]. Because of its fatty acid composition, palm oil can readily be fractionated, i.e. partially crystallized and separated into a high melting fraction or stearin and a low melting fraction or olein. High-melting stearin may be used in oleo chemical applications, soaps, food emulsifiers and other industrial applications such as lubricating oil. Three main commercial processes for fractionating palm oil are in use: the fast dry process, the slow dry process and the detergent process all these processes lead to specific products of different quality with different yield and operating costs. The physical and chemical characteristics as well as the triglyceride compositions by high performance liquid chromatography (HPLC) of palm oil fractions from these industrial fractionation processes are given. Other varieties of products produced by specific fractionation are presented with analytical data: the superoleins, palm-midfractions and cocoa butter substitutes. Palm oil is semi-solid oil, sedimenting at room temperature even in tropical countries. Therefore, a fractional crystallization is required. Because of its triglyceride composition which includes substantial quantities of both low and high melting point triglycerides, palm oil can readily be crystallized by controlled cooling and separated into a low melting fraction, olein, and a high melting one called stearin [29, 43].

Table 4 shows some of the physical properties of palm oil. The apparent density is an important parameter from the commercial point of view since it is used for volume to weight conversions. It can also be used as a purity indicator. The density of an oil depends on its saponification value (molecular weight), iodine value (unsaturation), free fatty acid content, water content and temperature[10,50]. Approximately, density changes by +0.3 kg/m 3 for each unit increase in saponification value; +0.14 kg/m 3 for each unit increase in iodine value; -0.68 kg/m 3 for each degree °C increase in temperature; -0.2 kg/m for each 1% increase in free fatty acids, and +0.8 kg/m 3 for each 1% increase in water. These corrections refer only to determinations at the usual ambient and measuring temperatures, e.g. 20-60 °C. Thus, for practical purposes the temperature is the most important variable. The most comprehensive study of the density of palm oil has been made by PORIM. Crude and RBD palm oil and olein were studied over the temperature range 25-75°C. Statistical analysis of the data showed no significant difference between the various oils, and the density could be expressed as density (g/ml) = 0.9244 - 0.00067 T, where T is the temperature in degrees Celsius. The solid fat content of oil is a measure (in percent) of the amount of solid fat present in the oil at any one Temperature. It is measured by means of wide-line nuclear magnetic resonance (NMR) spectrometry after a standard tempering procedure for the samples [4].

**Table 4.** Major physical properties of palm oil

| **Property** | **Mean (215 Samples)** | **Range** |
|---|---|---|
| **Apparent density at 50 °C (g/mL)** | 0.889 | 0.888 - 0.889 |
| **Refractive index at 50 °C** | 1.455 | 1.455 - 1.456 |
| **Solid fat content** | | |
| **5 °C** | 60.5 | 50.7 - 68.0 |
| **10 °C** | 49.6 | 40.0 -55.2 |
| **15 °C** | 34.7 | 27.2 - 39.7 |
| **20 °C** | 22.5 | 14.7 - 27.9 |
| **25 °C** | 13.5 | 6.5 -18.5 |
| **30 °C** | 9.2 | 4.5 - 14.1 |
| **35 °C** | 6.6 | 1.8 -11.7 |
| **40 °C** | 4.0 | 0.0 -7.5 |
| **45 °C** | 0.7 | |
| **Slip melting point (°C)( +)** | 34.2 | 31.1 -37.6 |

Some physicochemical properties of palm oil and its fractions are outlined in Table 5[6].

**Table 5.** Physicochemical properties of palm oil and its fraction

| | **Palm oil** | **Palm Olein** | **Palm Stearin** |
|---|---|---|---|
| **Melting point (°C)** | 34.2 | 21.6 | 44.5 - 56.2 |
| **Relative density (50 °C/water at 25 °C)** | 0.89 - 0.92 | 0.91 - 0.92 | 0.88 - 0.92 |
| **Refraction index (η)** | 1.46 | 1.47 | 1.45 |
| **Moisture and impurities (%)** | 0.1 | 0.1 | 0 - 0.15 |
| **Iodine Value** | 47 - 55.83 | 55.0 - 61.54 | 21.6 - 49.4 |
| **Saponification value (mg KOH/g)** | 196 - 208.2 | 189 - 198.0 | 193 - 206 |
| **Unsaponifiable matter (%)** | 0.01 - 0.5 | 0.001 -0.5 | 0.1 - 1.0 |

The solid present in the oil at any one temperature is due to the process of crystallization occurring in the oil as a consequence of its chemical properties. The different molecular triglyceride structures with their differing chemical characteristics manifest their physical states at different temperatures, thus imparting certain crystallization and melting behavior to the oil. These thermally associated processes can be followed by means of differential scanning calorimetry (DSC), Figures 3 and 4 show the crystallization and melting thermogram of palm oil respectively. In the crystallization thermogram, points 1 to 2 define the olein crystallization peak while points 2 to 3 define the stearin crystallization peak. These are defined by points 1 to 2 and 2 to 3, respectively, in the melting thermogram [4,58]. Palm oil, palm stearin, hydrogenated palm oil and hydrogenated palm olein were crystallized at 5°C temperature cycled between 5°C and 20°C and kept isothermally at 5 °C for 36 days. The polymorphic state of the fats was monitored by X-ray diffraction analysis. Soft laser scanning of X-ray films was used to establish the increase in β crystal content. Palm stearin was least stable in the β´ form, followed by palm oil. The hydrogenated oils were very stable in the β´ form. DSC analysis was used to complement the X-ray data. Palm oil can also be hydrogenated to yield products with various iodine values and melting points[58].

To conclude, the crystallization is a dynamic reaction where the molecules of triglycerides are in equilibrium. Many parameters such as the oil composition, the temperature, the polymorphism and the inter solubility may influence this equilibrium. Therefore, depending on the crystallization method used, the quality as well as the yield of the fractions will be affected. The availability of palm oil fractions has given opportunity for greater adaptability to specific requirements. The palm oil fractions from single and double stage blended or not with other oils followed or not by interesterification, may give new markets. As striking examples we find the superoleins and especially the palm mid-fractions where throughput and cost consideration are of less importance for the high value product [43] .

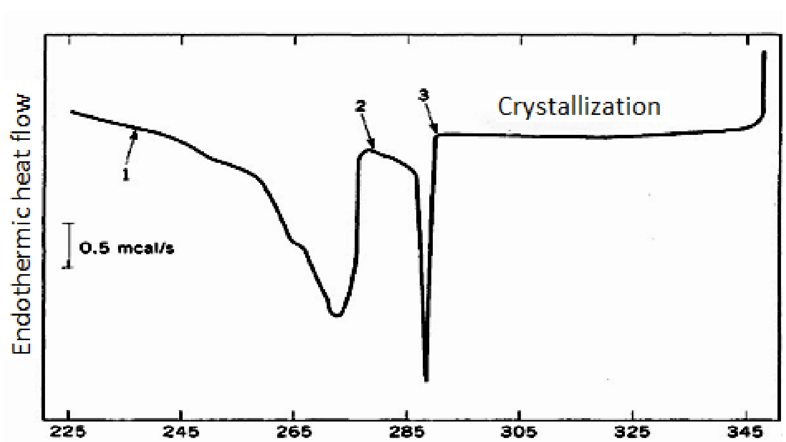


**Figure 3.** Crystallization thermogram of Malaysian palm oil[4]

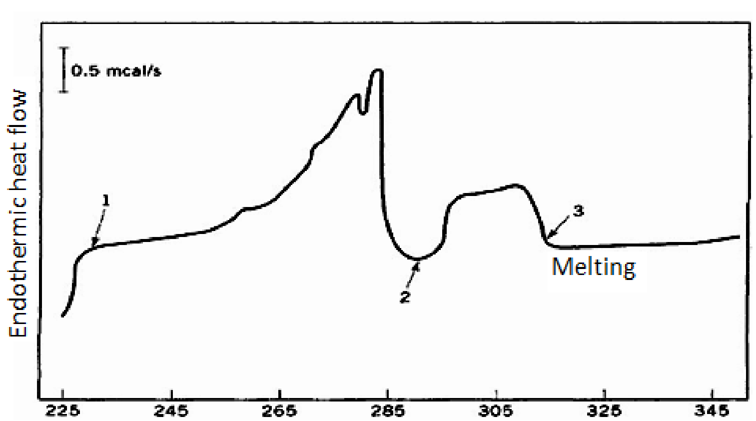


**Figure 4.** Melting thermogram of Malaysian palm oil[4]

**Table 6.** Melting and solidification characteristics

| **Tests** | **Oleins** | **Mean** | **Stearin** |
|---|---|---|---|
| | **Range** | | **Range** |
| **Slip melting point (°C)** | 19.4 - 23.5 | 21.6 | 44.5 |
| **Cloud point (°C)** | 6.6 - 14.3 | 1.4 | 56.2 |
| **Neutralized** | 5.4 - 11.9 | 8.1 | ___ |
| **Refined** | 6.0 - 11.5 | 8.8 | ___ |

It can be seen that palm oil can be separated under controlled thermal conditions into two components, a solid (stearin) and a liquid (olein) fraction. A range of stearin with differing Chemical and physical properties could be produced, yet keeping the chemical and physical properties of the oleins to within a very narrow range of values as shown in Table 6. It is the variations in the structure and number of carbons in these fatty acid chains that largely define the chemical and physical properties of palm oil. The chain lengths of the fatty acids present in the triglycerides of palm oil fall within a very narrow range from 12 to 20 carbons[4].

Dry fractionation is based on differences in the melting points of TAG which will crystallize selectively during the cooling process. Unfortunately, limitations due to inter solubility, closely linked to polymorphism; induce formation of co-crystals at each crystallization step. For this reason, only restricted TAG enrichments are observed. In this work, a series of samples of palm oil, solid and liquid fractions (stearin, mid fractions, oleins and superoleins) have been selected and examined in terms of TAG composition (by HPLC), DSC melting profile and variable temperature powder X-ray diffraction pattern. Three major endotherms [low-melting, high melting and very high-melting peaks (LMP, HMP and VHMP)] are detected in the DSC melting profiles (5-7 C/min). The VHMP is only recorded for palm stearin which contains more SSS components. The HMP contribution is weak for palm olein and even not observed for palm super oleins. The LMP is usually made up of UUU, SUU and SUS components; SUS components are observed in both LMP and HMP; the HMP is also made up of some SSS, except for palm oleins and super oleins. Sub-α2, sub-α1, α, β’2,β’1 and β polymorphic forms are recorded; the LMP components preferentially crystallize in sub-a2, sub-a1 and a forms; the HMP components generally crystallize in β’2 and β’1, with a tendency to exhibit β crystals, depending on the SSS content. Components of the VHMP have an increased tendency to stabilize in the β form; in view of the results, we can assume that there is a clear relationship between TAG composition, melting properties and polymorphic behavior and of palm oil and fraction[14] .

The keeping quality of the oils is basically dependent on their chemical compositions, for instance, the percentages of the degree of unsaturation[47]. Random analyses of samples of refined palm oil, palm olein, and palm stearin have shown the presence of about 2% of 1, 2-diglycerides and about 4% of 1, 3-diglycerides with trace amounts of monoglycerides. These partial glycerides are important as they are known to affect the crystallization behavior of the oil. Inherent Chemical Properties of Malaysian Palm Oil, summarized in Table 7[4]. Carotenoids degradation is strongly activated by the temperature. The thermal degradation of carotenoids in palm oil followed 1.3 order reaction kinetics. The reason for the fractional order may be due to the high antioxidant content in the oil; therefore the initial oil quality and the heat treatment have a major influence on the retention of carotenoids.

**Table 7.** Inherent chemical properties of Malaysian palm oil

| **Chemical Characteristics** | **Mean** | **Range** |
|---|---|---|
| **Saponification value (mg KOH/g oil)** | 195.7 | 190.1 - 201.7 |
| **Unsaponifiable matter (%)** | 0.51 | 0.15 - 0.99 |
| **Iodine value** | 52.9 | 50.6 - 55.1 |
| **Slip melting point** | 34.2 | 30.8 - 37.6 |

As a conclusion, in order to obtain oil with higher carotene content, it is more interesting to work at low temperatures for a long time instead of a higher temperature for a shorter treatment. However, under the usual refining conditions, the stripping of FFA to the desired level demands high temperatures. For that reason, the production of red palm oil requires the use of alternatives technologies such as a modified deodorization process, which should be preceded by chemical deacidification steps in order to remove the FFA to the required level and retain maximum content of all the important biologically active constituents. Meanwhile the dependence of constant rates with temperature obeyed the Arrhenius relationship. The activation energy for the carotenoids thermal degradation in palm oil was found to be 109.4 kJ/mol[60].

Many studies show that, the influence of partial replacement of palm olein (POo) with olive oil (Oo), (25 and 50%, w/w) was investigated during five consecutive days of frying. The results indicated that frying performance of POo was significantly ($P < 0.05$) influenced by partial replacement with olive oil. The highest change in peroxide value (PV), anisidine value (AV), totox value (TV), total polar compound (TPC), viscosity and melting point was shown by the control sample; whereas the replacement of 50% (w/w) palm olein with 50% (w/w)olive oil exhibited the least changes in PV, AV, TV, TPC, viscosity and melting point during the frying process[61].

Meanwhile Degumming is the first stage in refining, and it is used to precipitate metal salts and other hydrate phosphatides and mucilaginous materials likely to cause the oil to develop flavors and odors, and induces neutralization. Results show that, the effects of degummed type and strength of degumming reagent on the chemical and physical characteristics of edible vegetable oils are very important [62].

## Nutrition

Palm oil contains a high concentration of natural carotenoids of 500-700 ppm [18-23]. The main carotenes present in crude palm oil are β-carotene (56%) and α-carotene (35%). Both β-carotene and α-carotene are provitamin A. All carotenoids are destroyed during the normal refining processes. Processes are available to refine red palm oil without destroying the carotenoids. There are about 11 different carotenoids in crude palm oil .The major carotenoids of palm oil are Alfa and beta carotene; together they constitute more than 80% of the total carotenoids in palm oil[19,20]. Carotenes, in particular beta carotene and, to a lesser extent, Alfa carotene are known for their provitamin A activities, as they are transformed into vitamin A in vivo. Compared with other sources of natural carotenoids, palm oil has 15 times more retinol equivalents than carrots and 300 times more than tomatoes [18]. Studies have also strongly associated beta carotene with the prevention of certain types of cancer, such as oral, pharyngeal, lung and stomach cancers[18,24-26] .

The vitamin E content of palm oil is partially lost as a result of processing. For example, it has been reported that RBD palm oil, palm olein and palm stearin retain approximately 69, 72 and 76% of the original level of vitamin E in the crude oils, respectively. However, there is a large variation in these estimates within the refining industry because differences in the plant conditions as well as the plant design influence the amount of vitamin E lost during refining. It has been observed that vitamin E tends to partition preferentially into the olein fraction during fractionation of palm oil. For example, the concentration of vitamin E in RBD palm olein and RBD palm stearin were 104±135% and 57±75%, respectively of the original level of vitamin E in the source RBD palm oil [49].

Almost 90% of the world palm oil productions are as food. This has made demands that the nutritional properties of palm oil and its fractions be adequately demonstrated. The results of a large number of nutrition trials in animals and humans have been published. These studies have indicated that not only demonstrate the nutritional adequacy of palm oil and its products but have also caused transitions in the understanding of the nutritional and physiological effects of palm oil, its fatty acids and minor components [49]. The results have shown that palm oil is as good as the indigenous oils, in some instances even better in its cholesterolemic response to the other oils and fats studied[58,63].Palm oil is an excellent choice for food manufacturers because of its nutritional benefits and versatility. The oil is highly structured to contain predominantly oleic acid at the sn2-position in the major triacylglycerols to account for the beneficial effects described in numerous nutritional studies [64].

Red palm oil is a highly nutritious premium vegetable oil because of the presence of carotene, vitamin E, ubiquinones, and phytosterols. It is versatile edible oil that can be used in various food applications .The oil can be fractionated into a number of fractions with different physicochemical properties, thereby further extending its range of food applications[65].Therefore Commercial red palm olein (CRPOo) is a richest and safest source of phytonutrients, vitamin E and carotenoids. These components exist in comfortable concentration, suitable for consumption for all individuals .Furthermore these components are well retained for up to 12 months of storage under three simulated storage condition prevalent in Malaysia, namely supermarket (20°C), kitchen (30°C) and warehouse (40 °C) conditions [66].

There may be some justifiable concern about the nutritional and health impact of palm oil as an edible oil, in view of its relatively higher saturated fatty acid content and lower linoleic acid content, as compared to most of the other vegetable oils (with the exception of coconut oil) currently consumed in India. Since palm oil is going to be used as an additional edible oil, its nutritional and health impact have to be assessed as a complementary source of fat to the currently used edible oils [67]. But the nutritional properties of palm oil have been demonstrated since the 80's and specifically reported [68]. Where it was described that although palm oil contains 50% long chain saturated fats, it has a distinct antithrombotic effect based on observations from an animal study on arterial thrombogenesis in vivo. These observations became more prominent in many more studies carried out subsequently [64]. Later hypothesized that palm oil does not increase cardiovascular risk because the oil is highly structured to contain predominantly oleic acid at the stereo specific numbers (Sn) -2 position in the major triacylglycerols (TAG) . More recently, the report of an Expert Consultation on Fats and Fatty Acids in human nutrition has noted that "there is possible evidence to suggest that the total cholesterol (TC) and low density lipoprotein cholesterol (LDL-C) raising effects of palmitic acid are lower for vegetable than animal sources because it is present predominantly in the sn-1 and sn-3 position as opposed to sn-2 position as in animal fats such as lard". As such, palm oil, like other vegetable oils, including olive oil, has the favorable oleic acid in this position. Therefore, this will lead to an acceptance that palm oil is as good as olive oil. This will also explain why even though 50% saturated, palm oil behaves more like a monounsaturated fat [58].

A novel application of diacylglycerol (DAG) emerged in the late 1990s as a healthier form of oil, with a focus on the nutritional properties provided by the glyceride structure of DAG. DAGs are digested and metabolized differently from other oils, which significantly reduces the risk of obesity. DAGs consist of a glycerol backbone esterifies with two fatty acids (FA). DAGs have two isomeric forms, the sn-1, 3-DAG and the sn-1, 2(2, 3)-DAG, with a natural isomeric ratio of approximately 7:3. DAGs are found as minor components of various edible oils. Notably, DAG has the same bioavailability and physiological fuel value as TAG. There are two main health benefits of DAGs. First, the regular consumption of DAG oil in the diet has been shown to affect body weight and body fat in both animals and humans. Second, DAG oil has been shown to lower serum triglyceride (TG) levels when compared with conventional oils. Consequently, oils with high concentrations of DAG have drawn attention as useful oils for use in various food applications. The safety issues of DAG oil have been evaluated by the Japanese Ministry of Health and Welfare, and DAG oil has been classified as a "Food for Specified Health Use"; moreover, the FDA in the United States classified the oil as GRAS (Generally Regarded as Safe). Healthier DAGs can be applied in O/W emulsions, such as mayonnaises and salad dressings, and in W/O emulsions, such as margarines, spreads, creamy fillings, confectionary foods, shortening, fried products (potato chips, fried cakes, and doughnuts), icings and ice creams. Recently, DAG has been marketed as functional cooking oil in Japan and in

United States .The production of DAG usually results in a mixture containing MAG, DAG, and TAG through an enzymatic and purification process. In addition, the free hydroxyl group and nutritional benefits of DAG allow for many product possibilities, such as the use of DAG in foods, cosmetics, dietary supplements, and pharmaceuticals. Palm olein-based diacylglycerol oil (POL-DAG) is a pale yellowish liquid fraction obtained from the dry fractionation of palm oil after crystallization under a controlled temperature. The purified POL-DAG appears in semisolid form at room temperature. POL-DAG is less saturated than palm oil. To produce POL-DAG, palm oil undergoes a two-step glycerolysis process, and the purified product contains 35.6% C16:0, 46.5% C18:1 and 12.2% C18:2. POL-DAG can be blended with other vegetable oils to suit various fat applications. Furthermore, palm oil has many applications in the food industry, and many healthful solid fat products can be produced from palm-based DAG [69].

It must also be emphasized, however, that while evaluating the possible effects of any edible fat on blood cholesterol, the counteracting or the potentiating influence of habitual diets with which the oil is consumed, must be taken into account. A number of promotive and preventive factors of hypercholesterolemia are normally present in habitual diets. The balance of these factors present in any diet does ultimately determine the possible hyper- or hypocholesterolemic potential of palm oil. The influence of the habitual diets and their composition on the health effects of palm oil as an edible oil, has not been closely examined hitherto [67].

Studies indicated that a combination of palm oil with rice bran oil can significantly lower serum lipids in rats as compared to those given diet containing palm oil alone[70].

Compelling data have linked dietary Trans fatty acids to increased risk of cardiovascular heart disease. Evidence from large epidemiological studies, involving 667 to 80,082 men and women in different age groups, followed over 6 to 20 years, consistently found a positive association between Trans fatty acid intake and risk of cardiovascular heart disease. Controlled feeding dietary intervention studies have demonstrated that Trans fatty acids intake compared to cis-unsaturated fats and saturated fats increases LDL-C concentrations, reduces HDL-C concentrations, which consequently increases the TC: HDL-C ratio, a better predictor of cardiovascular heart risk. The recent interim report from FAO/WHO Expert Consultation also stated that there is convincing evidence that intake of trans fatty acid decreases HDL-C and increases the TC:HDL-C ratio in comparison to SFA (C12:0-C16:0), cis MUFA and PUFA[71] . Also reported that a 2%increase in energy intake from partially hydrogenated fats or trans fatty acids was associated with a 23% increase in the incidence of cardiovascular heart disease. Current evidence also suggests that Trans fatty acids may be implicated in the risk of sudden cardiac death and metabolic syndrome components. The increasing use of artificially produced Trans fats in foods therefore drew grave concern from the public, and led to stricter regulatory measures globally. Consequently, the US Food and Drug Administration required mandatory Trans fatty acids labeling on packaged foods from January 1, 2006, prompting food manufacturers to find alternatives to commercially-hydrogenated vegetable oils for bakery products, margarines, and fried foods. In this context, palm oil provides the best natural replacement for commercially produced hydrogenated vegetable oils, as it is naturally solid[58,72].

High fiber foods start to gain much attention in the industrial world, due to its importance in human health for treating and prevention wide range of diseases. Finding new and cheap source of dietary fiber is highly needed. Palm kernel cake which is wastes produced after oil extraction from palm kernels is increasing in volume as the oil palm industry expands in many parts of Asia and Africa. The results showed that the palm kernel with testa contains the highest amount of the total dietary fiber with 63.06 g/100g sample, crude fiber 8.49 g/100g, crude protein content 14.40 g/100g, ash 4.43 g/100g sample with $p < 0.05$. The mean moisture content of the Palm Kernel with testa was 3.26 which is least than the other samples. Moreover, the defatted palm kernel with testa considered superior than the defatted palm kernel without testa and palm kernel cake, and could be used as a good and cheap source of dietary fiber for human consumption [73].

The effect of consuming palm oil exclusively as the visible or cooking fat in different socioeconomic groups of urban and rural areas of India country is shown in Table 8. It can be seen that the intake of palm oil as an exclusively edible oil does not compromise the EFA intake of any of the socioeconomic groups, the total EFA intake remains at 4-5% energy in all the groups [67].

Table 8.The effect of Replacing the Visible Fat with Palm Oil on EFA Intake of Different Socioeconomic Group in India

| Social Group | Visible fat intake (g/day) | Linoleic acid intake | | | En % |
|---|---|---|---|---|---|
| | | Invisible fat | Palm oil (g/cu/day) | Total | |
| **Urban:** | | | | | |
| **High Income Group (HIG)** | 46.0 | 11.6 | 4.8 | 16.4 | 5.7 |
| **Middle income Group (MIG)** | 35.0 | 10.0 | 3.6 | 13.6 | 5.2 |
| **Low Income Group (LIG)** | 22.0 | 10.7 | 2.3 | 13.0 | 5.2 |
| **Rural (average)** | 9.0 | 10.2 | 0.9 | 11.1 | 4.4 |

Tocotrienols, a group of vitamin E stereoisomer's, over many health benefits including their ability to lower cholesterol levels, and provide anticancer and tumor-suppressive activities. A diet rich in tocotrienols, especially dietary tocotrienols from a tocotrienol-rich fraction (TRF) of palm oil, reduced the concentration of plasma cholesterol and apolipoprotein B, platelet factor 4, and thromboxane B2, indicating its ability to protect against platelet aggregation and endothelial dysfunction. Red palm oil is one of the richest sources of carotenoids; together with vitamin E, tocotrienols, and ascorbic acid present in this oil, it represents a powerful network of antioxidants, which can protect various tissue and cells from oxidative damage. For rat hearts, α-tocotrienol were more proficient in the protection against oxidative stress induced by ischemia-reperfusion than a-tocopherol. Tocotrienols are found to be more effective in central nervous system protection compared to a-tocopherol. In another study, TRF is found to inhibit the glutamate-induced pp60c-src kinase activation in HT4 neuronal cells [74-77]. Extracellular matrix deposition is key event for the development of bowel stenosis in Crohn's disease patients. Transforming growth factor-b plays a key role in this process. We aimed at characterizing the effects of tocotrienol rich fraction on Extracellular matrix (ECM) proteins production and molecules that regulate the synthesis and degradation of extracellular matrix, matrix metalloproteinase-3 and tissue inhibitor of metalloproteinases-1, in human intestinal fibroblasts, and at elucidating whether the effects of tocotrienol rich fraction (TRF) are mediated through inhibition of Tocotrienol-rich fraction (TGF-b1). Results show that TRF from palm oil significantly diminished procollagen 1 and 3 synthesis in Tocotrienol-rich fraction (HIF)[78].Other minor palm oil components that demonstrate major nutritional and health benefits, so micronutrients are listed in Table 9[42].

RPO in the maternal diet was shown to improve the vitamin A status of lactating mothers and their infants. Consumption of RPO incorporated in a sweet snack or biscuits significantly improved plasma retinol concentrations in children with subclinical vitamin A deficiency. There is evidence that if only 35-50% of the recommended daily intake for vitamin A were to be provided by RPO[81]**.** The emphasis on the world's nutritional problem has shifted from lack of protein (or energy) to the importance of certain micronutrients such as vitamin A. Vitamin A status is an important factor in children morbidity and mortality in developing countries.

Vitamin A deficiency is one of the major public health nutritional problems in many developing countries, particularly those in Africa, Asia and the Western Pacific .

The deficiency of vitamin A, the leading cause of preventable blindness in children, is often associated with protein-energy malnutrition, parasitic infestation and diarrhea disease and can result in a range of developmental and pathological states, such as heart, lung and eye defects.

**Table 9.** 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 -tocopherol | 44 -73[a] |
| β -tocopherol | 44 -73[a] |
| γ - tocopherol | 262 -437[a] |
| δ - tocopherol | 70 -117[a] |
| Total Tocotrienols | 1000 -1200[a] |
| Phytosterols | 326 -527[b] |
| Phospholipids | 5 - 130[b] |
| Squalene | 200 -500[b] |
| Ubiguniones | 10 - 80[b] |
| Aliphatic alcohols | 100 -200[b] |
| Triterpene alcohols | 40 -80[b] |
| Methyl sterols | 40 -80[b] |
| Aliphatic hydrocarbons | 50[b] |

a: O'Brien (2010)[79], b: Zou et al. (2012)[80]

The characteristic color of Red palm oil RPO is due to the abundance of carotenoids (500–700 mg/l) in the crude oil. RPO is the richest natural source of β-carotene (375 mg/g) , the most abundant carotenoid that can be converted to vitamin A, which is also an antioxidant that destroys singlet oxygen and free radicals. Although there have been many reports on the effects of some vegetable oils on plasma lipids, there appears to be no available reports on the impact of feeding palm oil (red or refined) on the vitamin A status of animals. The results suggest that consumption of palm oil in moderate amounts enhances growth of tissues and bioavailability of β-carotene, which may combat vitamin A deficiency in developing countries, in view of the fact that preformed vitamin A in animal products (namely meat, liver, eggs and fatty fish) is out of the reach of economically deprived people [82]**.** Besides, it is very rich in *β*-carotene (provitamin A) and vitamin E[10,54,55] .

Malnutrition in early childhood has received increasing attention in recent years because of its widespread occurrence in developing areas throughout the world. Vitamin A, because of its relation to growth and implication in xerophthalmia, is particularly important in the young child Oey Khoen Lian reported that deficiency of vitamin A is the largest single cause of blindness in Java. So Red palm oil, 4 ml daily, was given to children from 1 to 5 years of age in two communities as a source of provitamin A .Therefore effect of this diet was significant[83]**.**

Palm oil is a rich source of tocotrienols which have been reported to have anti tumor activity against certain types of transplantable murine tumors. Palm oil is a rich source of tocotrienols which have been reported to have anti tumor activity against certain types of transplantable murine tumors [84].

## CONCLUSION

The oil is semi-solid at room temperature; it does not require hydrogenation. Palm oil has a unique fatty acid and TAG, 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. The major fatty acid in palm oil are meristic, palmitic, stearic, oleic and linoleic. CPO is used for cooking, frying, and as a source of vitamins. 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 food applications . Because of high saturated fatty acid content, it has a high oxidative stability and suitability for frying. Palm oil is being used increasingly in foods such as cooking oils, margarines, shortenings, icecream and confectionery products. Palm oil could be blended with different edible oils without modifying the original taste of the oil, but with some slight color change. 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. The minor components of interest in palm oil are vitamin E and carotenoids. The beta carotene of palm oil may be important to correct vitamin A deficiency in addition to protecting against certain forms of cancer such as stomach cancers, oral, pharyngeal, and lung cancers. Palm oil, at moderate levels, is completely safe and non toxic. Palm oil can be fractionated into stearin and olein. Meanwhile this feature is the well-known cost effective attributes of palm oil and its compatibility in various food formulations for keeping more safety and healthy. The fatty acid composition of palm oil has thus been the focus of attention in determining its nutritional adequacy in relation to coronary heart disease risk factors.

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