Palm Oil: Chemistry and Nutrition Updates

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Abstract

The palm fruit (*Elaies* guineensis) yields palm oil, a palmitic-oleic rich semi solid fat and the fat-soluble minor components, vitamin E (tocopherols, tocotrienols), carotenoids and phytosterols. A recent innovation has led to the recovery and concentration of water-soluble antioxidants from palm oil milling waste, characterized by its high content of phenolic acids and flavonoids. These natural ingredients pose both challenges and opportunities for the food and nutraceutical industries. Palm oil's rich content of saturated and monounsaturated fatty acids has actually been turned into an asset in view of current dietary recommendations aimed at zero *trans* content in solid fats such as margarine, shortenings and frying fats. Using palm oil in combination with other oils and fats facilitates the development of a new generation of fat products that can be tailored to meet most current dietary recommendations. The wide range of natural palm oil fractions, differing in their physico-chemical characteristics, the most notable of which is the carotenoid-rich red palm oil further assists this. Palm vitamin E (30% tocopherols, 70% tocotrienols) has been extensively researched upon for its nutritional and health properties, including antioxidant activities, cholesterol lowering, anti-cancer effects and protection against atherosclerosis. These are attributed largely to its tocotrienol content. A relatively new output from the oil palm fruit is the water-soluble phenolic-flavonoid-rich antioxidant complex. This has potent antioxidant properties coupled with beneficial effects against skin, breast and other cancers. Enabled by its water solubility, this is currently being tested for use as nutraceuticals and in cosmetics with potential benefits against skin aging. A further challenge would be to package all these palm ingredients into a single functional food for better nutrition and health.

INTRODUCTION

The oil palm is a monocotyledon belonging to the genus *Elaeis.* It is a perennial tree crop and the highest oil producing plant, yielding an average of 3.7 tonnes of oil per hectare per year in Malaysia. The crop is unique in that it produces two types of oil. The fleshy mesocarp produces palm oil, which is used mainly for its edible properties and the kernel produces palm kernel oil, which has wide application in the oleochemical industry. The genus *Elaeis* comprises two species, namely *E. guineensis* and *E. oleifera.*[1] *E. guineensis* originates from West Africa and the commercial planting material is mainly of this species. *E. oleifera* is a stumpy plant of South American origin and its oil is characterised by a high oleic acid content. Currently, most of the world's production of palm oil comes from South-East Asia, in particular Malaysia and Indonesia. Malaysian crude palm oil production increased from 8.3 million tonnes in 1998 to 11.2 million tonnes in 2002, maintaining the country's position as the world's largest supplier of palm oil. Currently palm oil accounts for about 13% of the total world production of oils and fats and is expected to overtake soybean oil as the most important vegetable oil.

ORIGIN

Elaies guineensis originating from West Africa was first introduced to Brazil and other tropical countries in the 15th Century by the Portuguese.[2] However, its propagation did not take off until the 19th Century when the Dutch brought seeds from West Africa to Indonesia resulting in four seedlings planted in Bogor, Indonesia in 1848. The palms were *dura* and the progenies from these seedlings were planted as ornamentals in Deli and became known as Deli *Dura*. From there the oil palm was sent to the Botanical Gardens in Singapore in 1875, and subsequently brought to Malaya (as West Malaysia was then known) in 1878. The oil palm was initially planted in Malaya as an ornamental and the first commercial planting was only in 1917.

Elaeis oleifera from South America has higher oleic and linoleic acid content and lower content of palmitic and other saturated acids. The iodine value ranges from 78-80. The current main interest in *E. oleifera* is in the potential of transmitting its useful characters to interspecific hybrids with *E. guineensis*.

The oil palm fruit is a drupe, which forms in a tight bunch. The pericarp comprises three layers: the exocarp (skin); mesocarp (outer pulp containing palm oil); and endocarp (a hard shell enclosing the kernel (the endosperm) which contains oil and carbohydrate reserves for the embryo). Fruit development starts at approximately two weeks after anthesis (WAA). Oil deposition in the endosperm starts at approximately 12 WAA and is almost complete by 16 WAA.[3] During this period the endosperm and endocarp slowly harden and by 16 WAA the endocarp is a hard shell enclosing a hard white endosperm – the kernel. Oil deposition in the mesocarp starts at approximately 15 WAA and continues until fruit maturity at about 20 WAA. The fruits on a bunch do not ripen simultaneously owing to slight variation in the time of pollination. Fruits at the end of each spikelet ripen first and those at the base last. Fruits on the outside of the bunch are large and deep orange when ripe while the inner fruits are smaller and paler.

In the commercial Malaysian *tenera* variety, the neutral lipids, especially triacylglycerols (TG), increase rapidly from 16 WAA onwards, along with the parallel accumulation of total lipids, reaching their maximum at 20 WAA. The polar lipids simultaneously decrease to less than 1% of the total lipids at 20 WAA. The Nigerian *dura* variety follows a similar pattern except that rapid TG accumulation occurs between 18-22 WAA.

Palmitoleic and linolenic acids are present in significant amounts in the early stages of lipid synthesis. These are typical chloroplast and membrane fatty acids, reflecting a high ratio of chloroplast and cellular synthesis to storage lipid synthesis. These fatty acids however are undetectable after 16 WAA, probably greatly diluted by the accumulation of storage lipids. The immature mesocarp contains large amounts of chlorophyll which decline by about 17 WAA, accompanied by a massive accumulation of carotenes as the fruit ripens.[4] Also characteristic of the immature green mesocarp are large amounts of sterols. As the fruit matures, the sterols decrease as a consequence of dilution by the tremendous amount of TG synthesised.

CHEMISTRY OF PALM OIL

Like all oils, TGs are the major constituents of palm oil. Over 95% of palm oil consists of mixtures of TGs, that is, glycerol molecules, each esterified with three fatty acids. During oil extraction from the mesocarp, the hydrophobic TGs attract other fat- or oil-soluble cellular components. These are the minor components of palm oil such as phosphatides, sterols, pigments, tocopherols, tocotrienols and trace metals. Other components in palm oil are the metabolites in the biosynthesis of TGs and products from lipolytic activity. These include the monoglycerols (MGs), diglycerols (DGs) and free fatty acids (FFAs).

The fatty acids are any of a class of aliphatic acids, such as palmitic (16:0), stearic (18:0) and oleic (18:1) in animal and vegetable fats and oils. The major fatty acids in palm oil are myristic (14:0), palmitic, stearic, oleic and linoleic (18:2).[5] The typical fatty acid composition of palm oil from Malaysia is presented in ***Table 1*.** Palm oil has saturated and unsaturated fatty acids in approximately equal amounts.

Most of the fatty acids are present as TGs. The different placement of fatty acids and fatty acid types on the glycerol molecule produces a number of different TGs. There are 7 to 10% of saturated TGs, predominantly tripalmitin.[6] The fully unsaturated TGs constitute 6 to 12%. The Sn-2 position has specificity for unsaturated fatty acids. Therefore, more than 85% of the unsaturated fatty acids are located in the Sn-2 position of the glycerol molecule. ***Table 2*** shows the percentage distribution of individual TGs of palm oil. The triacylglycerols in palm oil partially define most of the physical characteristics of the palm oil such as melting point and crystallisation behaviour.

MINOR CONSTITUENTS OF PALM OIL

The minor constituents can be divided into two groups. The first group consists of fatty acid derivatives, such as partial glycerides (MGs, DGs), phosphatides, esters and sterols. 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.[7]

Most of the minor components found in the unsaponifiable fraction of palm oil are sterols, higher aliphatic alcohols, pigments and hydrocarbons. The other minor components, such as partial glycerides and phosphatides, are saponifiable by alkaline hydroxide.

The partial glycerides do not occur naturally in significant amounts except in palm oil from damaged fruits. Such oils would have undergone partial hydrolysis resulting in the production of free fatty acids, water and the partial glycerides.

Different isomers of MGs and DGs are found in palm oil. -MGs are more stable than their -isomers. As in most vegetable oils, the , '-DGs (or 1,3 DGs) are the predominant DGs in palm oil.

Several minor nonglyceride compounds are found in palm oil. **Table 3** gives the levels of these minor components in the oil. The nonglyceride fraction of palm oil consists of sterols, triterpene alcohols, tocopherols, phospholipids, chlorophylls, carotenoids and volatile flavour components, such as aldehydes and ketones.

Sterols are tetracyclic compounds with generally 27, 28 or 29 carbon atoms. They make up a sizeable portion of the unsaponifiable matter in oil. The total content of sterols in palm oil is about 0.03%. Cholesterol (2.2-6.7%), 5-avenasterol (0-2.8%) 7-stigmasterol (0-2.8%) and 7-avenasterol (0-4%) was also found in the sterol fraction (326- 627 mg/kg) of palm oil[168]. Most of the sterols are relatively inert and do not appear to contribute to any important property to palm oil. However, 5-avenasterol has been reported to show antioxidant activity in edible oils.

Tocopherols and tocotrienols are fat-soluble vitamin E isomers and the major antioxidants of vegetable oils. Tocopherols can be divided into two families, namely tocols and tocotrienols. In tocols, the side chain is saturated while in tocotrienols it is unsaturated. Tocotrienols are rarely seen in other vegetable oils with the exception of palm, rice bran and corn oil. Crude palm oil contains 600 to 1000 ppm of tocols and tocotrienols. Refining reduces the level down to 350-630 ppm (***Table 4***). Both tocols and tocotrienols are composed of four different isomers, referred to as or , depending upon the number and position of methyl groups attached to the chromane rings. The major vitamin E isomers in palm oil are -tocotrienol (44%), -tocopherol (22%) and -tocotrienol (12%). The others are the - and -tocotrienols and -, - and -tocopherols.[8] Besides playing a beneficial biological role as radical quenchers *in vivo*, tocopherols and tocotrienols are also antioxidants, which contribute to the stability of palm oil. Tocopherols can interrupt lipid oxidation by inhibiting hydroperoxide formation in the chain-propagation step, or the decomposition process by inhibiting aldehyde formation. Besides its free radical scavenging activity, -tocopherol is highly reactive towards singlet oxygen and protects the oil against photosensitised oxidation.

The pigmentation of palm fruits is related to their stage of maturity. Two classes of natural pigments occuring in crude palm oil are the carotenoids and the chlorophylls.

Palm oil from young fruits contains more chlorophyll and less carotenoids than oil from mature or ripe fruits. The pigments in palm oil are involved in the mechanisms of autoxidation, photooxidation and antioxidation within the plant.

Carotenoids are highly unsaturated tetraterpenes biosynthesized from eight isoprene units. Their more favoured state is the all-*trans*. Carotenoids are divided into two main classes: carotenes, which are strictly polyene hydrocarbons, and xanthophylls, which contain oxygen. The oxygen in xanthophylls may be in the form of hydroxy (e.g. zeaxanthin and lutein), keto, epoxy or carboxyl groups. The simplest carotene is lycopene.

Crude palm oil has a rich orange-red colour due its high content of carotene (700 – 800 ppm). The major carotenoids in palm oil are - and -carotene, which account for 90% of the total carotenoids.[10] There are about 11 different carotenoids in crude palm oil. The major types and composition of carotenoids **(*Table 5*)** extracted from oils of different palm species were studied by Yap et al.[10] They found 13 different types of carotenoids with the major isomers, -carotene and -carotene, accounting for 54% to 60% and 24% to 60% of the total carotenoids, respectively. No significant difference in the types of carotenoids was found in the oils of *E. oleifera* and *E. guineensis*, and their hybrids and backcrosses to *E. guineensis*. The study also showed that *E. guineensis* contained a higher level of lycopene compared to *E. oleifera* and its hybrids with *E. guineensis.*

Carotenoids are the precursors of vitamin A, with -carotene having the highest provitamin A activity. Palm oil has 15 times more Retinol Equivalents than carrot and 300 times more than tomato. Carotenes are sensitive to oxygen and light. The oxidation of carotenes is accelerated by hydroperoxides generated from lipid oxidation, leading to discoloration and bleaching. - and -ionones, -13 and -14-apocarotenals and -13-apocrotenone are among the products formed from the oxidative deterioration of carotenoids.

In refining crude palm oil, the carotenoids are first partially removed by adsorption on an activated earth, following which high temperature steam deodorization destroys the chromogenic properties of the remaining carotenoids to produce a light yellow refined palm oil. With carotene as a rich source of vitamin A, a process was developed by Choo and co-researchers[11] to produce a deacidified and deodorised red palm oil which retains as much as 80% of the original carotenoids. A red palm oil produced from this process, bearing the trade name 'CAROTINO', is available in the market.

The fatty acid composition of palm oil (≈1:1 saturated to unsaturated fatty acids) is such that the oil is semi-solid at normal room temperature. This property and the oil melting range permit its use as a major component in margarine and shortening without hydrogentation.[12] Thus, for most practical purposes, palm oil does not need hydrogenation. Nonetheless, the use of this process has been explored to maximise the utilisation of palm oil and its fractions in edible food products. Palm stearin is an excellent and economic starting material for certain food and non-food applications where fully hydrogenated fats are required. Cake shortenings made from palm oil products such as hydrogenated or interesterified palm oil, in combination with butterfat, produce cakes with better baking properties than cakes made with 100% butterfat. Whereas the butterfat gave the cakes the desired buttery flavour, the palm products enhanced the baking performance. Some hydrogenated products of palm oil and its products are also suitable for application in a number of high premium speciality products, such as toffee and confectionery fats.

Apart from palm oil and the fat-soluble minor constituents described above, the palm fruit contains large amounts of water-soluble phenolic compounds and flavonoids. These are basically extracted into the steriliser condensate and the palm oil milling effluent (POME) during the milling process. The sterilisation of palm fruits inactivates polyphenoloxidases and retains the phenolics and flavonoids. These are water soluble and demonstrated to have potent entioxidant properties.[13] A recent technology developed at the Malaysian Palm Oil Board (MPOB) uses an ecologically friendly process in which the constituent water added during the sterilisation of palm fruits is used to retain the compounds of interest for passage through a series of innovative separation techniques that isolate specific compounds of interest on the basis of their molecular weights. The final aqueous product can be further processed depending upon its intended applications.

NUTRITIONAL PROPERTIES OF PALM OIL AND ITS COMPONENTS

Almost 90% of the world palm oil production is used as food. This has made demands that the nutritional properties of palm oil and its fractions be adequately demonstrated. 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 (CHD) risk factors. As mentioned earlier, palmitic acid (44%) is the major saturated fatty acid in palm oil and this is balanced by almost 39% monounsaturated oleic acid and 11% polyunsaturated linoleic acid. The remainder is largely stearic (5%) and myristic (1%) acids. This composition is significantly different from palm kernel oil (obtained as a co-product during the processing of oil palm fruits) which is almost 85% saturated. The results of a large number of dietary trials in animals and humans have been published and reviewed previously.[7] These studies have yielded results 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.

The minor components of interest in palm oil are the vitamin E, carotenoids and an antioxidant-rich phenolic-flavonoid complex recovered from the palm oil milling waste. The technology to isolate and concentrate these components has led to their use in several studies aimed at understanding their physiological effects. Accordingly, the emphasis has been on the cholesterol lowering effects of palm oil tocotrienols, the pro-vitamin A activity of red palm oil and palm carotene concentrates and the antioxidant and anti-cancer properties of palm vitamin E, carotenoids and the phenolic-flavonoid complex. These findings currently supported by a large volume of scientific publications, which are discussed briefly.

Human Studies

Effects of palm oil / olein as part of a low-fat healthy diet. Palm oil when consumed as part of a low-fat diet (<30% energy) has been shown to be effective in maintaining desirable plasma cholesterol and lipoprotein cholesterol levels.[14] Monounsaturated oils rich in oleic acid are currently touted to be the healthiest of the edible fats in the human diet. While olive, rapeseed and Canola have in excess of 60% of their fatty acid composition as cis-oleic acid, palm olein has about 48% of this monounsaturated fatty acid. The question of whether this level of oleic acid in palm olein is adequate to result in a lipoprotein-cholesterol profile that protects against coronary heart disease (CHD) was examined in a series of human trials. In these studies the exchange between palm olein (rich in 16:0) and olive oil (rich in 18:1) resulted in similar plasma and lipoprotein cholesterol values (total cholesterol, TC, low-density lipoprotein cholesterol, LDL-C and high density lipoprotein cholesterol, HDL-C). This showed that in healthy normocholesterolaemic humans, palm olein could be exchanged for olive, Canola and rapeseed oils (high oleic) without adversely affecting serum lipids and lipoprotein levels.[14]

Sundram *et al.*[15] fed 23 healthy normocholesterolaemic male volunteers carefully designed whole food diets containing canola oil (18:1-rich), palm olein (16:0-rich) or an American Heart Association Step 1 diet (AHA), all contributing approximately 31% en fat and < 200mg dietary cholesterol/day. The AHA oil blend was obtained by blending soyabean oil (50%), palm oil (40%) and canola oil (10%) which resulted in a 1:1:1 ratio of the saturates, monounsaturates and polyunsaturates. Serum TC and LDL-C were not significantly affected by these three diets despite manipulations of the key fatty acids. The high 18:1 canola and high 16:0 palm olein resulted in almost identical plasma and lipoprotein cholesterol. Only HDL-C after the AHA diet was significantly raised compared with the other two diets. The findings of the above study have now become the subject of a patent[16] advocating a balanced fatty acid ratio for maintaining a proper LDL/HDL-cholesterol ratio that could be cardio-protective.

When the habitual Dutch diet, which is characteristic of a typical Western diet, was maximally replaced with palm oil (~ 80% replacement) TC and LDL-C was unaffected. The palm oil diet however resulted in significant improvements in the HDL2-C and the apolipoprotein A1/B ratio signalling some cardiovascular benefits rather than the converse.[17]

The above-mentioned studies focussed on the oleic acid content in the different oils tested (palm olein, canola, rapeseed and olive) for their cholesterol modulating properties. Undoubtedly, oleic aicd has been proven to have cholesterol-lowering properties, which are said to equal or better than those of the polyunsaturates. However, the optimum amount of oleic acid required to produce beneficial lipoprotein profiles has yet to be defined. In this context, palm olein containing 44%-48% oleic acid was equal in its plasma cholesterol and lipoprotein modulating effect to those of higher oleic acid containing oils including olive (70%), canola (65%) and rapeseed (60%). This augers well for palm olein and its apparent lack of cholesterolemic effects.

Effects of palm oil / olein in comparison to saturated fats. The human diet contains a mixture of fats, and, therefore, mixtures of fatty acids. The net effect of such a mixture on TC, individual lipoproteins or both will be the sum effects of all the fatty acids, some acting in opposite directions to each other. It is therefore important to decipher the key cholesterol modulating fatty acids to determine the cholesterolaemic index of the fat or oil consumed. Fortunately, several recent human studies have focussed on these issues and have provided additional observations that tend to support the Hegsted[18] observation that saturated fatty acids differ in their cholesterol regulating ability. Some of these studies that used palm oil as a source of 16:0 in their test diets demonstrated that the cholesterolaemic effect due to 16:0 (palmitic acid) is significantly lower than that of a lauric+myristic (LM, 12:0+14:0) combination. Coconut oil is almost 85% saturated and it has been suggested that the higher cholesterol values after a coconut oil diet may be simply due to the lower availability of linoleic acid. This suggestion has been discounted in the recent study of Sundram *et al.*[19] Despite the incorporation of a high level of 18:2 (5.6% en) into the LM diet, it induced significantly higher concentrations of TC and LDL-C in healthy volunteers compared to a 16:0-rich palm olein diet (3.3% en as 18:2).

From the studies cited above we can see that the effect of palmitic acid (the major saturated fatty acid in palm oil products), on plasma lipoprotein cholesterol is becoming better understood. Indeed, if palmitic acid is hypercholesterolemic, then an increased endogenous synthesis or a decreased clearance rate of cholesterol should be evident. The human study of French *et al*.[20] investigated the relationship between endogenous synthesis of cholesterol and the content of palmitic acid in the diet contributed by palm oil. High levels of palmitic acid in the diet did not significantly affect serum total and LDL-cholesterol levels. Fractional synthetic rate of cholesterol was not different between dietary treatments (high versus low palmitic acid content). This suggested that there was no relation between endogenous synthesis of cholesterol and palmitic acid content in the diet.

Effects of palm oil / olein in comparison to* trans *fatty acids*.* *Trans* fatty acids negatively impact human plasma lipoprotein profile and have untoward implications for atherogenesis. *Trans* fatty acids deleteriously affect lipoproteins by increasing TC, LDL-C, lipoprotein Lp(a) and decreasing HDL-C relative to their *cis isomers*[21]. This has raised the need to replace hydrogenated fats with natural solid fats in a large number of food formulations. The nutritional efficacy of the solid fats replacing hydrogenated fats should be such that they do not adversely affect plasma lipids and other CHD risk factors. In this context, palm oil can be considered a suitable alternative. In several studies the impact of *trans* elaidic acid on the lipoprotein profile of humans appeared to be worse than that of saturates occurring in natural oils and fats[22].

The solid fat profile of palm oil makes it a natural contender to replace hydrogenated fats in solid-fat food formulations. The use of palm oil in such products could virtually eliminate their *trans* fatty acid content. The desired fatty acid composition in the product can be easily achieved by blending palm and other oils. For example, this has been demonstrated previously in the AHA-blend,[15,16] in which palm olein contributed 40% of the blend's composition and this resulted in an optimum LDL/HDL-cholesterol ratio.

MINOR COMPONENTS IN PALM OIL AND THEIR HEALTH EFFECTS

Some of the minor components in palm oil include the carotenoids, tocopherols, tocotrienols, sterols, phosphatides, triterpenic and aliphatic alcohols. Although these minor components account for less than 1% of the oil's constituents, they nevertheless play significant roles in maintaining its stability and quality. In addition, some of these minor components especially the carotenoids and vitamin E (tocopherols and tocotrienols) are of nutritional importance.

PALM VITAMIN E

Refined palm oil contains about 350-450ppm vitamin E, present as the RRR- -tocopherol (30%) and tocotrienol (70%) isomers. In contrast, other oils such as corn, soya and sunflower are good sources of the tocopherols but contain no tocotrienols. Historically, vitamin E activity (one international unit, IU) has been defined as 1mg of all rac- -tocopheryl acetate whereas 1mg of RRR- -tocopherol equalled 1.49 IU. In addition, vitamin E activity in foods is expressed as the -tocopherol equivalent (-TE), which is the activity of 1mg of RRR- -tocopherol[23]. On this basis, conversion factors for of each mg of the different tocopherols and tocotrienols present in palm oil to -TE are as follows: -tocopherol, 1.0; -tocopherol, 0.5; -tocopherol, 0.1; -tocotrienol, 0.3 and -tocotrienol, 0.05. The factors for gamma and delta tocotrienols are presently unknown. These conversion factors are based on the ability of each isomer to overcome specific vitamin E deficiency symptoms such as foetal resorption, muscular dystrophy and encephalomalacia. Since these factors are based on rat foetal resorption assays[24], their relevance to humans is often questionable. In addition, their biological activity may be based on their antioxidant activities, but this too appears misleading. For example, -tocotrienol has only one third the biological activity of -tocopherol, yet it has a higher or equivalent antioxidant activity.[7]

There is now a growing interest in the nutritional and physiological properties of vitamin E in palm oil, especially those of the tocotrienols. This has recently been reviewed.[25,26] Tocotrienols have attracted great interest for their suggested ability to regulated plasma cholesterol levels by the inhibition of HMG-CoA reductase (HMGR) activity, which regulates cholesterol synthesis in the liver. The current data is however conflicting with respect to the ability of tocotrienols from different sources to beneficially lower plasma cholesterol in humans.

Palm tocotrienols may have potential anti-cancer properties. Sundram *et al.*[27] suggested that crude palm oil was more effective than refined palm oil in increasing the tumour latency period in DMBA treated rats. This was attributed to the presence of tocotrienols and carotenoids in the crude oil. When the vitamin E content in palm oil was removed, significantly more tumours became apparent[28]. Addition of palm vitamin E to corn oil (500 or 1000ppm) resulted in a lower tumour incidence and occurrence compared to rats fed corn oil alone.

A series of studies also investigated the *in vitro* effects of tocotrienols on human breast cancer cells. Compared to -tocopherol (500ug/ml concentration), which had no growth inhibition of human breast cancer cells, palm TRF inhibited the incorporation of (3H) thymidine into human breast cancer cells by 50% (at a concentration of 180ug/ml)[29]. Osterogen-receptor negative and positive human breast cancer cells were used to test the efficacy of individual palm tocotrienols at varying concentrations. These individual tocotrienols showed even greater inhibitory effects on these cells and at much lower concentrations than TRF. There also appears to be a synergy in the inhibition of human cancer cells between palm tocotrienols and flavonoids. Combinations of tocotrienols, flavonoids and tamoxifen proved to be even more effective than the individual components (Guthrie *et al.*, 1997b).[30] Palm tocotrienols have also been reported to be effective against transplantable mice tumours.

PALM CAROTENOIDS

The mesocarp of the oil palm fruit yields a deep red coloured palm oil, which contains 700-800ppm carotenoids. The characteristics of these palm carotenoids and technological advances aimed at producing red palm oil and palm carotene concentrate have been discussed earlier. The pro-vitamin A activity of carotenoids has been known for a long time. Only a few carotenoids are provitamins, and those that are vary in their bioavailability. ß-carotene is the most important vitamin A precursor in human nutrition and provides the major source of vitamin A in many developing countries.

ß-carotene-rich red palm oil has been used in dietary intervention studies to evaluate its possible role in the prevention of vitamin A deficiency among populations at risk. In India, children 5-10 years old with keratomalacia were treated twice a day with an emulsion prepared with red palm oil. Each dose contained 0.6ml of red palm oil and therapy was continued for 15 days. The red palm oil treatment compared well with the results obtained by treating another group of keratomalacia patients with cod liver oil containing a similar dose of vitamin A.

Red palm oil is the richest natural source of ß-carotene, a precursor of vitamin A, in addition to providing energy density to the diet. Rukmini[31] summarized some aspects of the health and nutritional effects of red palm oil and the results of a comprehensive safety evaluation was carried out by the Indian Council for Medical Research at the National Institute of Nutrition. The purpose of this work was to recommend use of the oil in supplementary feeding programmes. Based on the results obtained, it was recommended that developing countries should have no hesitation in creating strategies to increase the use of red palm oil in combating vitamin A deficiency. The importance of red palm oil in the treatment of vitamin A deficiency has been reiterated by many others[32]. These are easy to produce, available all year round, inexpensive and accessible sources of vitamin A for most of the developing world.

It was also observed that red palm oil could be blended with different edible oils without modifying the original taste of the oil, but with some slight colour change. The League of Nations Intergovernmental Conference on Rural Hygiene in the late 1930s recognized and recommended the possibility of making use of red palm oil as a source of pro-vitamin A in malnourished populations. The XVllth meeting of the International Vitamin A Consultative Group in Guatemala[33], recommended among other measures, the use of red palm oil because its carotenoid content seems to be particularly bioavailable. Similar recommendations have also been made in a United Nations report[34]. Dietary intervention with red palm oil thus offers a good degree of protection from severe vitamin A deficiency.

Palm Carotenoids and cancer prophylaxis. Doll and Peto[35] identified diet as one of the major factors in the aetiology of cancer. Cancer epidemiological studies have provided evidence that cancer chemopreventive agents exist naturally in our diets. High intakes of vegetables and fruits are known to be associated with lower risk of cancer of the lung and gastrointestinal tract. The protective effect may relate to different components present in fruits and vegetables. Although, over one thousand compounds have been tested, the retinoids and carotenoids have received the most attention. A number of epidemiological studies have demonstrated an inverse correlation between dietary intake or blood level of vitamin A/carotenoids and cancer risk, as well as an anti-carcinogenic effect for these compounds. The data further indicate that a wide range of cancer sites may be influenced by these carotenoids.

The inhibition of chemical carcinogenesis by palm oil carotenoids with reference to Benzo(a) pyrene metabolites *in vivo* and *in vitro* in rat hepatic cells has been reported by Tan and Chu.[36] It has also been reported that palm carotenoids exhibit an inhibitory effect on the proliferation of a number of human cancer cells. These include the neuroblastoma, GOTO, pancreatic cancer PANC-1, glioblastoma A172 and gastric cancer HGC-27.[37] Of significant interest from these studies was the observation that palm alpha-carotene and a palm carotene concentrate were protective whereas synthetic beta-carotene was tumour promoting. Murakoshi *et al.*[38] isolated palm alpha-carotene and a palm carotene concentrate and showed its ability to inhibit liver, lung and skin tumours in mice. The same effect could not however be attributed to synthetic beta-carotene. Similar superior inhibitory effects for alpha-carotene were apparent in a chemically induced skin tumour progression model. Overall, these results lead to the conclusion that the natural bouquet of carotenoids, in palm oil has promising chemopreventive activities against cancer.

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Table 1: Typical fatty acid composition (%) of palm oil

Fatty acid chain length	Mean	Range observed	Standard deviation
12:0	0.3	0 - 1	0.12
14:0	1.1	0.9 – 1.5	0.08
16:0	43.5	39.2 – 45.8	0.95
16:1	0.2	0 – 0.4	0.05
18:0	4.3	3.7 – 5.1	0.18
18:1	39.8	37.4 – 44.1	0.94

18:2	10.2	8.7 – 12.5	0.56
18:3	0.3	0 – 0.6	0.07
20:0	0.2	0 – 0.4	0.16

Table 2: Triacylglycerol composition (%) of Malaysian *tenera* palm oil

No Double Bond		1 Double Bond		2 Double Bonds		3 Double Bonds		≥4 Double Bonds	
MPP	0.29	MOP	0.83	MLP	0.26	MLO	0.14	PLL	1.08
PMP	0.22	MPO	0.15	MOO	0.43	PLO	6.59	OLO	1.71
PPP	6.91	POP	20.02	PLP	6.36	POL	3.39	OOL	1.76
PPS	1.21	POS	3.50	PLS	1.11	SLO	0.60	OLL	0.56
PSS	0.12	PMO	0.22	PPL	1.17	SOL	0.30	LOL	0.14
PSP	-	PPO	7.16	OSL	0.11	OOO	5.38		
		PSO	0.68	SPL	0.10	OPL	0.61		
		SOS	0.15	POO	20.54	MOL	-		

		SPO	0.63	SOO	1.81				
				OPO	1.86				
				OSO	0.18				
				PSL	-				
Others	0.16		0.34		0.19		0.15		0.22
Total	9.57		33.68		34.12		17.16		5.47

Kifli (1981)[6]

M, myristic; P, palmitic, S, stearic; O, oleic; L, linoleic

Table 3: Ranges in content for various components in the unsaponifiable fraction of palm oil

Component	%	Mg/kg (in palm oil)
Carotenoids		500 - 700
-carotene	36.2	
- carotene	54.4	
-carotene	3.3	
Lycopene	3.8	
Xanthophylls	2.2	
Tocopherols		
-tocopherols	35	
	35	

-tocopherols	10	500 - 800
- tocopherols	10	
+ -tocopherols		
Sterols		
Cholesterol	4	
Campesterol	21	300
Stigmasterols	21	
-sitosterol	63	
Phosphatides		500 - 1000
Total alcohols		
Triterpenic alcohol	80	800
Alipahtic alcohol	20	

Table 4: Tocopherol and Tocotrienol Content (mg/kg) of Common Refined Edible Oils

Tocol Isomers	Soybean oil	Corn Oil	Olive Oil	Sunflower Oil	Milk fat - ghee	Wheat germ oil	Rice bran oil	Palm Oil	Palm Olein	Palm Stearin
Tocopherol	117.2	248.9	151.4	485.2	32.7	218.9	64	188.2	179.0	50.0
	19.8	10.1	13.3	3.0	n.d.	33.2	10.6	n.d.	n.d.	n.d.
Tocopherol	560.7	464.1	10.9	51.0	n.d.	84.7	n.d.	n.d.	17.6	n.d.
Tocopherol	178.2	58.2	n.d.	n.d.	33.8	n.d.	187	n.d.	n.d.	n.d.
Tocopherol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	31.4	198.1	219.9	47.4
Tocotrienol	20.2	n.d.	n.d.	n.d.	n.d.	347.5	83.2	10.0	8.1	9.0
Tocotrienol	6.2	n.d.	n.d.	8.3	n.d.	n.d.	783.2	198.8	332.7	134.9
Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	18.4	38.6	98.4	67.0	31.4

Tocotrienol										
Total	902.2	781.4	175.6	547.5	66.5	702.7	1198	693.5	824.3	272.8

Table 5: Carotene profiles of palm oil extracted from Elaeis guineensis, Elaeis Oleifera and their hybrids

	Carotene Composition (%)						
	M	**P**	**D**	**MP**	**MD**	**MD x P**	**T**
Phytoene	1.12	1.68	2.49	1.83	2.45	1.30	1.27
Cis- -carotene	0.48	0.10	0.15	0.38	0.55	0.42	0.68
Phytoene	Trace	0.90	1.24	Trace	0.15	Trace	0.06
-carotene	54.08	54.39	56.02	60.53	56.42	51.64	56.02
-carotene	40.38	33.11	54.35	32.70	36.40	36.50	35.16
Cis- -carotene	2.30	1.64	0.86	1.37	1.38	2.29	2.49
-carotene	0.36	1.12	2.31	1.13	0.70	0.36	0.69

-carotene	0.09	0.48	1.10	0.23	0.26	0.19	0.33
-carotene	0.09	0.27	2.00	0.24	0.22	0.14	0.83
Neurosporene	0.04	0.63	0.77	0.23	0.08	0.08	0.29
-zeacarotene	0.57	0.97	0.56	1.03	0.96	1.53	0.74
-zeacarotene	0.43	0.21	0.30	0.35	0.40	0.52	0.23
Lycopene	0.07	4.50	7.81	0.05	0.04	0.02	1.30
Total carotene (ppm)	4592	428	997	1430	2324	896	673

Yap et al[10]

*M = *E. oleifera* (Melanococca), P = *E. guineensis (pisifera),* D = *E. guineensis (dura)*

*T = *E. guineensis (tenera)*