Palm oil: A healthful and cost-effective dietary component

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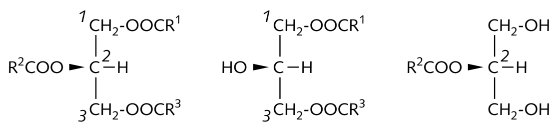
Abstract

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. Oil quality and nutritional benefits have been assured for the variety of foods that can be manufactured from the oil directly or from blends with other oils while remaining trans-free. The oxidative stability coupled with the cost-effectiveness is unparalleled among cholesterol-free oils, and these values can be extended to blends of polyunsaturated oils to provide long shelf-life. Presently the supply of genetic-modification-free palm oil is assured at economic prices, since the oil palm is a perennial crop with unparalleled productivity. Numerous studies have confirmed the nutritional value of palm oil as a result of the high monounsaturation at the crucial 2-position of the oil's triacylglycerols, making the oil as healthful as olive oil. It is now recognized that the contribution of dietary fats to blood lipids and cholesterol modulation is a consequence of the digestion, absorption, and metabolism of the fats. Lipolytic hydrolysis of palm oil glycerides containing predominantly oleic acid at the 2 position and palmitic and stearic acids at the 1 and 3 positions allows for the ready absorption of the 2-monoacylglycerols while the saturated free fatty acids remain poorly absorbed. Dietary palm oil in balanced diets generally reduce blood cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides while raising the high-density lipoprotein (HDL) cholesterol. Improved lipoprotein(a) and apo-A1 levels were also demonstrated from palm oil diets; an important benefit also comes from the lowering of blood triglycerides (or reduced fat storage) as compared with those from polyunsaturated fat diets. Virgin palm oil also provides carotenes apart from tocotrienols and tocopherols that have been shown to be powerful antioxidants and potential mediators of cellular functions. These compounds can be antithrombotic, cause an increase of the prostacyclin/thromboxane ratio, reduce restenosis, and inhibit HMG-CoA-reductase (thus reducing) cholesterol biosynthesis). Red palm oil is a rich source of β-carotene as well as of α-tocopherol and tocotrienols.

Introduction

Oils and fats are macronutrients for humans, who need to consume about 20 to 25 kg per capita per year, as recommended by the World Health Organization (WHO). People in some countries consume excessive amounts of oils and fats—about 40 to 50 kg per capita—with adverse effects on health; in contrast, a number of the most populous countries in the world consume only about 8 to 9 kg per capita per year, which is inadequate. For good health, one needs a balanced diet, including oils and fats that supply energy and essential fatty acids. There are many sources of oils and fats, but soybean oil, palm oil, sunflower seed oil, and rapeseed oil contribute 60% to 70% of the world's production.

All oils and fats have the triacylglycerol or triglyceride structures shown below. Their differences lie in the types of fatty acids (RCOOH) attached to the glycerol backbone in positions 1, 2, and 3.



Triacylglycerol (TAG) or Triglyceride | **1,3-Diacylglycerol (DAG)** | **2-Monoacylglycerol (MAG)**

Fats and oils are classified simply as saturated, monounsaturated, and polyunsaturated depending on

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which fatty acids are dominant, but with many newly developed crop oils, the three classifications may be less clearly defined.

There are a number of well-known facts about vegetable oils:

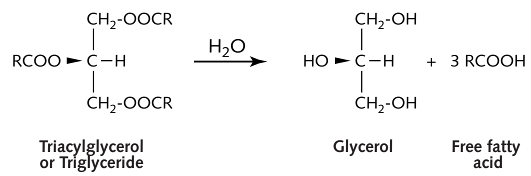
» Fatty acids from plant oils are mainly unsaturated at the 2 position of the glyceride structure. Cocoa butter and palm oil can be considered highly structured, having the 2-positional fatty acids mainly unsaturated and the 1,3-fatty acids mainly saturated.
» Vegetable oils and fats, in contrast to animal fats, are cholesterol-free.

Food manufacturers use oils and fats in their different forms for specific products. Their choice of oils and fats depends on quality and technical performance.

Quality

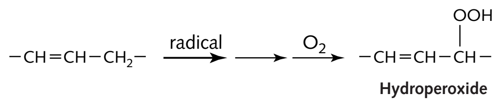
The quality of oils is dependent on their resistance to two major chemical reactions:

Hydrolysis



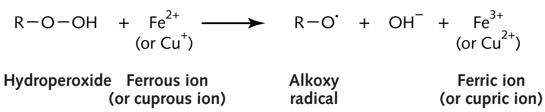
The hydrolysis reaction occurs slowly in the presence of water but is catalyzed by lipase enzymes as well as acid.

Oxidation



Oxidation is mediated by initiating free radicals to produce more radicals from fat molecules, which then readily combine with oxygen, a diradical ($^{\bullet}O–O^{\bullet}$), of air to give hydroperoxy radicals and then hydroperoxides. In special circumstances oxygen can be in the singlet state, $^1O_2$; singlet oxygen is in the excited state and is more reactive. The oxidized products usually proceed to generate more radicals, which will cause the destruction of more oil molecules.

For example:



Breakdown products of oxidation cause rancid odors, and furthermore the consumption of oxidized oils is highly suspected to cause undesirable biochemical reactions. Oxidative stability is therefore an important factor in the formulation and processing of foods. A summary of the role of free radicals in nutrition, health, and disease can be obtained from several reviews [1, 2].

The quality of the oil also takes into account its nutritional attributes, in particular its effects on cardiovascular diseases and possibly cancer. The role of fats in health and nutrition should be evaluated in the context of the digestion, absorption, and metabolism of lipids. Triacylglycerols with long-chain fatty acids are mainly hydrolyzed by the pancreatic lipase to 2-monoacylglycerols or 2-monoglycerides (see structures above) and free fatty acids from positions –1 and –3 of the triglycerides (shown in fig. 1). The ease or difficulty of absorption of these components will affect their subsequent metabolism and finally their role, if any, in cardiovascular diseases [3, 4].

It is the 2-monoacylglycerols that are readily absorbed in the intestine to be re-esterified again to triacylglycerols. The rate of absorption of the free fatty acids depends on the nature of the acids and the emulsifying medium in the intestine. Long-chain saturated fatty acids are poorly soluble and form insoluble calcium and magnesium salts. These acids require greater concentrations of bile than the unsaturated fatty acids for absorption. In the case of palm oil, the fatty acids in the 2-monoacylglycerols are mainly unsaturated (87%), although overall 50% of the fatty acids in the three positions of triacylglycerols are saturated, a consequence of having the 1- and 3-positional fatty acids more highly saturated. There are two very important dietary consequences. First, the absorbed fatty acids are mainly mono- and diunsaturated (87% for palm oil and up to 96% for palm olein), despite the relatively high saturation in the total glycerides (see tables 1–3) [4–9]. Second, the relatively high content of saturated free fatty acids in digested palm oil in comparison to other highly unsaturated oils and fats,

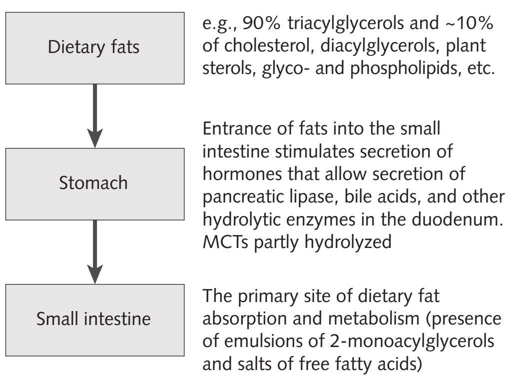


FIG. 1. Digestion, absorption, and metabolism of fats

will be less absorbed and therefore contribute less to caloric intake and serum triacylglycerols. Assuming that all the unsaturated fatty acids at the 1- and 3-positions in palm oil are preferentially absorbed while the saturated fatty acids from these same positions are excreted as salts, then only 8% of saturated fatty acids from the 2-position will be absorbed, an ideal situation to enhance the nutritional attribute of palm oil. Studies indicate that the fatty acids in the 2-position of the triacylglycerols have been highly conserved in the digestive process [10–13]. Research has also suggested that dietary cholesterol needs to be re-esterified with unsaturated fatty acids before it is incorporated into chylomicrons and transported by intestinal lymph. Therefore, palm oil fatty acids will be expected to contribute less to the absorption of dietary cholesterol already in the bloodstream.

Technical performance

Quality must also be considered in the performance of the oil during processing. For example, during frying at 180°C, polyunsaturated oil undergoes extensive oxidation, giving rise to oxidized products and dimeric/oligomeric compounds. Similarly, ready biological oxidation of polyunsaturated molecules leads to reactive free oxy-radicals, which are harmful to human cells and genetic material. Although the polyunsaturated oil can be stabilized by hydrogenation to produce more saturated material, partial hydrogenation inevitably produces *trans* fatty acids, which have been shown to cause two undesirable effects: raising the “bad” low-density-lipoprotein (LDL) cholesterol and lowering the “good” high-density lipoprotein (HDL) cholesterol, both effects being considered harmful to the heart in the long term. Therefore, an oil with high oxidative stability, such as palm oil, which does not require hydrogenation in the majority of applications, would be the preferred choice over other vegetable oils. Furthermore, refined palm oil provides an organoleptic bland flavor ideally suited to enhance the various flavors of foods. A wide range of solid fat products, e.g., margarine and shortenings, are also needed in the marketplace, and this requirement means that polyunsaturated oils need to be partially

TABLE 1. Positional distribution of fatty acids in triacylglycerols in oils and fats

Oil	Positions	Fatty acid (mol%)											Major triacylglycerols[a]
		16:0	16:1	18:0	18:1	18:2	18:3	20:0	20:1	22:0	22:1	24:0	
Virgin palm oil	1, 2, 3	44.3		4.6	39	10.5							POP, POO
	2	11.0		2.0	65.0	22.0	—	—	—	—	—	—	PLO, PLP[b]
Palm olein	2	4.3			65.9	29.8							
Olive oil	1	13.1	0.9	2.6	71.8	9.8	0.6	—	—	—	—	—	OOO, OOP
	2	1.4	0.7	—	82.9	14.0	0.8	—	—	—	—	—	OLO
	3	16.9	0.8	4.2	73.9	5.1	1.3	—	—	—	—	—	
Soybean	1	13.8	—	5.9	22.9	48.4	9.1	—	—	—	—	—	LLL, LLO
	2	0.9	—	0.3	21.5	69.7	7.1	—	—	—	—	—	LLP
	3	13.1	—	5.6	28.0	45.2	8.4	—	—	—	—	—	
Rapeseed	1	4.1	0.3	2.2	23.1	11.1	6.4	—	16.4	1.4	34.9	—	
	2	0.6	0.2	—	37.3	36.1	20.3	—	2.0	—	3.6	—	
	3	4.3	0.3	3.0	16.6	4.0	2.6	—	17.3	1.2	51.0	—	
Corn	1	17.9	0.3	3.2	27.5	49.8	1.2	—	—	—	—	—	LLL, LOL
	2	2.3	0.1	0.2	26.5	70.3	0.7	—	—	—	—	—	LLP
	3	13.5	0.1	2.8	30.6	51.6	1.0	—	—	—	—	—	
Peanut	1	13.6	0.3	4.6	59.2	18.5	—	0.7	1.1[c]	1.3	—	0.7	OOL, POL
	2	1.6	0.1	0.3	58.5	38.6	—	—	0.3[c]	0.2	—	0.5	OLL
	3	11.0	0.3	5.1	57.3	10.0	—	4.0	2.7[c]	5.7	—	2.8	
Cocoa butter	1	34.0	0.6	50.4	12.3	1.3	—	1.0	—	—	—	—	POS, SOS
	2	1.7	0.2	2.1	87.4	8.6	—	—	—	—	—	—	SPO
	3	36.5	0.3	52.8	8.6	0.4	—	2.3	—	—	—	—	
Linseed	1	10.1	0.2	5.6	15.3	15.6	53.2	—	—	—	—	—	
	2	1.6	0.1	0.7	16.3	21.3	59.8	—	—	—	—	—	
	3	6.0	0.3	4.0	17.0	13.2	59.4	—	—	—	—	—	

Source: refs. 4–11.

a. L denotes 18:2, O 18:1, P 16:0, and S 18:0.

b. Major triacylglycerols are the same for virgin palm oil; approximately 5% diacylglycerols are also present.

c. Together with 18:3 *n*-3.

TABLE 2. Fatty acid (mol %) and triacylglycerol composition of some oils

Fatty acid	Butter (wt%)	Milk fat			Lard			Cocoa butter			Cod liver oil			Virgin palm oil	
		sn-1	*sn*-2	*sn*-3	*sn*-1	*sn*-2	*sn*-3	*sn*-1	*sn*-2	*sn*-3	*sn*-1	*sn*-2	*sn*-3	*sn*-1,-2 and -3	*sn*-2
4:0	4	5	2.9	43.3											
6:0	2	3.0	4.8	10.8											
8:0	1	0.9	2.3	2.2											
10:0	2	2.5	6.1	3.6											
12:0	3	3.1	6.0	3.5										0.2	
14:0	13	10.5	20.4	7.1	1	4	—				2	5	2	1.1	
16:0	26	35.9	32.8	10.1	10	72	7	34	2	37	12	14	6	44.3	11
18:0	13	14.7	6.4	4.0	30	2	73	50	2	53	5	1	1	4.6	2
18:1	28.5	20.6	13.7	14.9	51	13	18	12	87	9	35	9	25	39.0	65
18:2	3	1.2	2.5	0.5	6	3	—	1	9	—	1	1	1	10.5	22
18:3	0.5										—	—	—	[a]	
20:1											14	8	18		
22:0											3	11	11	[a]	
22:2											12	8	11		
22:6											1	3	1		
24:0											3	2	2		
Major triacylglycerols[b]	PPB, PPC				SPO, OPL, OPO			POS, SOS, SPO						POP, POO, POL, PLP	

Source: refs. 4–11.
a. 0.3% of 16:1, 18:3 *n*-3 and 20:0; *sn*-1, -2, and -3 = all 1, 2, and 3 positions, values averaged.
b. B denotes 4:0, C 10:0, L 18:2, O-18:1, P 16:0, and S 18:0.

TABLE 3. Saturated, monounsaturated, and polyunsaturated fatty acids in some oils and fats

Oil	Saturated (S)	Monounsaturated (M)	Polyunsaturated (P)	P/S ratio	U/S ratio	P2/S2 ratio	U2/S2 ratio
Rapeseed	5.0	71.0	24.0	4.8	19	95	166
Canola	7.0	61.0	32	4.67	13.3	155	330
Sunflower	11.7	18.0	68.6	5.9	7.4		
Olive	13.0	79.1	7.9	0.6	6.7	10.6	73
Corn	13.3	28.4	58.3	4.4	6.5	28	39
Soybean	16.0	23.5	60.5	3.8	5.3	64	85
Groundnut	20.0	38.7	41.3	2.1	4.0	14.8	38
Cottonseed	27.7	19.8	52.5	1.9	2.6	6.32	8.8
Lard	43.0	47.0	10.0	0.2	1.3	0.04	0.2
Palm olein	46.8	41.5	12.0	0.3	1.1	6.9	22
Palm	49.5	40.3	9.6	0.2	1.0	1.7	6.7
Cocoa butter	60.1	36.5	3.4	0.2	0.7	2.3	24
Butter	63.4	32.5	4.5	0.1	0.6	0.03	0.2
Hydrogenated soybean[a]	64.0 + *trans*	26.0	4.0	0.1	0.5		
Palm kernel	84.0	14.0	2.0	0.02	0.2		
Coconut	92.2	6.2	1.6	0.02	0.1	0.02	0.05

Source: refs. 7–9.
P/S and U/S: polyunsaturated/saturated and (monounsaturated + polyunsaturated)/saturated fatty acid ratios, respectively. P2, S2, U2: polyunsaturated, saturated, and total unsaturated fatty acids, respectively, from position-2 of the triglycerides.
a. Typical sample, saturated 22%, *trans* fatty acids 42%.

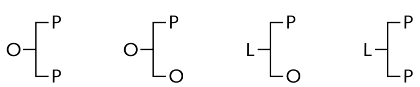
hydrogenated. This has been widely practiced for a long time (e.g., soybean oil), although it was known that the formation of *trans* fatty acids via partial hydrogenation is not desirable. To avoid this problem, a formulation of polyunsaturated oil blended with palm oil can be used to provide healthful *trans*-free products, and the additional benefit provided is the formation of the desirable polymorphic crystals, giving the food the appropriate texture. Also, in recent years, many consumers have been concerned about the consumption of genetically modified foods and these are now widespread in many oilseed crops. However, palm oil at the present time is assured to be 100% free of genetic modification.

Techno-economic considerations for palm oil

Manufacturers are always likely to choose raw materials that are in constant supply at economic prices. The oil palm is a perennial crop, and its high oil yield per planted hectare (8 to 10 times higher than that of any other oil) provides sufficient and reliable supplies. The world has been assured of good-quality palm oil for several decades. Information is available covering formulation, handling, storage, and transportation of palm oil and its products [14, 15].

Palm oil is the main oil from the oil palm and is derived from the mesocarp or flesh of the palm fruit. Being a fruit oil, it is like olive oil. The nut of the palm fruit contains the palm kernel from which a different oil (palm kernel oil) and palm kernel cake are obtained. Thus, from the oil palm fruit two types of oils are produced, which have totally different chemical and physical properties and different applications. Palm oil is mainly used for food, but palm kernel oil is mainly for the oleochemical industry. The differences need to be emphasized because they have caused confusion to those less acquainted with the oil palm crop. The distinctly different chemical compositions and physical properties that determine their varied applications are given in tables 1 to 3. Palm oil and palm olein (liquid fraction) have similar compositions to monounsaturated oil. However, palm kernel oil, with a high content of lauric acid, is practically interchangeable with coconut oil, and both oils have many applications, such as for surfactants, soap, and specialty fats. On the other hand, palm oil has a wide spectrum of applications in the food industry described below, and its potential is yet to be fully exploited.

The chemical composition of virgin palm oil (crude palm oil) shows that it contains mainly triacylglycerols (more than 95%), diacylglycerols, and free fatty acids (approximately 3.5%) and minor components (approximately 1%). There are more than 33 triacylglycerols with the major triglyceride as the symmetrical POP, POO, POL, and PLP glycerides (tables 1 and 2). The presence of the symmetrical triglycerides POP and PLP makes it possible to fractionate for cocoa butter equivalents for the manufacture of chocolates and confectioneries.



POP POO PLO PLP

P = palmitic; O = oleic; L = linoleic acid

The minor components of virgin palm oil contain a range of important, well-researched compounds, including tocotrienols (powerful antioxidants), carotenoids, phytosterols, squalene, diacylglycerols, etc. These compounds play a significant role in stabilizing palm oil as well as in the refinability of the oil. Extraction of some of these high-value compounds has provided several nutraceutical products [16–20].

The average Malaysian virgin palm oil does not contain more than 3.5% free fatty acids, and these are readily removed by physical refining to produce refined, bleached, and deodorized (RBD) palm oil. Dry fractionation of this oil yields palm olein (liquid fraction) and palm stearin (solid fraction). From these the refining industry produces 14 processed palm oils for various applications based on physical processes without the use of solvents, in contrast to seed oils such as soybean oil.

The specifications of processed palm oils have been published [14, 15]. The main processed products are RBD palm oil, RBD palm olein, and RBD palm stearin. The multiple applications of these products in the food industry are summarized in table 4, making palm oil a perfect partner in the food industry. Higher-value products of fractionation include superolein, top olein, and fractions for cocoa butter equivalents. Superolein, a relatively polyunsaturated fraction, and red palm oil, a carotene-enriched oil, are also readily available.

In addition to those in table 4, palm oil-based applications can be extended to the following:

Trans-free margarine formulation
Expanded and extruded snacks
Reduced fat spreads
Nuts (fried)
Bakery fat
Doughnuts
Cocoa butter replacers and equivalents
Milk with palm fat replacing milk fat
Manufacture of food emulsifiers
Palm-based processed cheese
Pastry
Yogurt with palm fat replacing milk fat
Flour confectionery
Soup mixes
Sugar confectionery
Salad dressing
Peanut butter
Cooking sauces
Frying chips (french fries)
Ready-made meals

Two applications in particular will be elaborated below. These are palm oil for frying and palm oil for margarines, shortenings, and vanaspati (a vegetable ghee).

TABLE 4. Food uses of some palm oil products[a]

Product	Palm oil	Palm olein	Palm stearin (soft)	Palm stearin (hard)	Hardened palm oil	Double fractionated palm olein	Palm mid-fraction	Palm kernel oil
Shortenings	xxx	xxx	xxx	xx	xxx	—	x	x
Margarines	xx	xxx	xxx	x	xxx	—	x	xxx
Frying fats	xxx	xxx	xx	—	xx	xxx	x	—
Cooking oil (warm climate)	—	xx	—	—	—	xxx	—	—
Fats and coating	—	—	xxx	—	—	—	x	xxx
Ice cream	xxx	—	—	—	xx	—	—	xxx
Biscuits	xxx	x	xx	x	xx	—	—	xx
Cookies	xxx	—	xx	x	xx	—	—	—
Crackers	xxx	x	xx	x	x	—	—	xxx
Cake mix	xxx	—	xx	x	x	—	—	—
Icings	xx	—	x	—	x	—	xx	—
Instant noodles	xxx	xxx	xx	—	xxx	—	—	—
Nondairy creamer	x	—	x	—	x	—	—	xxx

Source: refs. 14 and 15.
a. xxx, Major use; xx, moderate use; x, minor or specialized use.

Palm oil for frying

For deep-fat frying the conditions are severe, with temperatures at about 180°C under atmospheric oxygen. A host of reactions takes place, based mainly on free-radical oxidation and hydrolysis. The nature of the oil will be modified to produce derivatives of the original molecules known as polar compounds. For frying, palm olein is an excellent choice, and its superior frying quality may be compared with that of other oils. For example, after four days of frying with soybean, corn, and palm oils, the amounts of polar gums obtained were 3.4%, 3.1%, and 1.9%, respectively [21]. The stability of palm olein to free radical oxidation is due to its relatively high content of monounsaturated (oleic) and saturated fatty acids and to the presence of natural antioxidants such as tocotrienols. The performance of polyunsaturated oils such as soybean and sunflower seed oils is very poor, since they are easily oxidized, isomerized, and polymerized. Potato chips have less oil retention when fried in palm olein than when fried in polyunsaturated oils. To impart oxidative stability to the latter oils, they are hydrogenated. However, hydrogenation produces *trans* fatty acids, which have been demonstrated to be unhealthful (discussed in more detail below) because they raise "bad" LDL and lower "good" HDL cholesterol as well as participating in other biochemical reactions. Thus, palm olein is the preferred choice for industrial frying of potato chips, snacks, instant noodles, etc.

For home cooking, palm olein is suitable for shallow pan frying as well as deep frying (e.g., of potato chips). The oil can be reused several times. Consumers in temperate countries may observe cloudiness in the oil when the temperature drops below 20°C. This crystallization is purely a physical phenomenon and happens to all oils, but occurs at lower temperatures for polyunsaturated oils. Solid oils can be returned to their liquid state by warming them. This aesthetically undesirable aspect of the oil can be overcome by blending palm olein with other liquid oils. Blending will enable producers to market oils with the recommended ratios of saturates:monounsaturates:polyunsaturates as specified by various countries, usually in the range 1:1–1.7:0.6–1 [22]. The percentage of monounsaturates in the recommendations has been gradually increased at the expense of the polyunsaturates

Palm oil for margarines, shortenings, and vanaspati

Approximately 55% of the world's population consume liquid vegetable cooking oil, and the remaining 45% consume solid cooking fats. The latter group is used to consuming butter and ghee, which come from animal sources and are high in cholesterol and cholesterol oxide, which are perceived to have negative effects on the heart. As a result, many vegetable oils have been modified to resemble butter and ghee products. The main modification process is hydrogenation of liquid oils such as soybean, rapeseed, and sunflower oils. However, hydrogenation gives rise to unhealthful *trans* fatty acids. The natural solid-fat fractions of palm oil containing palmitic fatty acid render palm oil a suitable *trans*-free main ingredient in margarines, shortenings, and vanaspati. Furthermore, palm-based blends provide the desirable polymorphic crystal forms for the required textures and melting characteristics in a variety of margarines.

Nutrition

Some quarters have raised concern about the high content of saturated fatty acids and their implications for cardiovascular diseases. This simplistic inference needs correction. A person consuming oils and fats does not take in only the fatty acids; rather, it is the chemical nature of the triacylglycerols (see triacylglycerol formulas above), particularly the position of attachment of the fatty acids, that determines the final absorption and metabolism in the body. In the digestion and absorption of triacylglycerols, not only are the nature and chain length of the fatty acids important, but also the position of attachment (*sn* 1, 2, or 3) to the glycerol backbone plays a role in determining absorption and subsequently the levels of blood triacylglycerols and cholesterol. Minor components, such as tocotrienols, also play a role (e.g., by modulating the thromboxane/prostacyclin ratio) in reducing the aggregation of blood platelets, thus reducing the tendency of blood to clot. The most compelling evidence that palm oil does not cause harm to the heart is found in recent human experiments whose results have been published and are summarized below.

Recently increasing attention has been focused on triacylglycerol metabolism and uptake of the fatty acids at the three positions of the triacylglycerol molecules [3, 4, 12, 13, 23]. It is the 2-positional fatty acids that will play the most important role in the absorption of the fat, whereas the 1- and 3-positional fatty acids will be less absorbed, especially if they are long-chain saturated fatty acids. The phenomenon is being made use of in various nutraceutical foods with designed structured fats. For instance, infant formulas can contain triacylglycerols with 2-positional palmitic acid, with oleic acid occupying the other two positions. Apart from this, it may be noted that saturated acids such as palmitic acid are an important requirement in nutrition; for example, 1,2-dipalmitoyl-phospholipids are required for healthy lungs.

The problems of obesity and excessive intake of calories have been recent concerns, and to alleviate these, oils with suitably structured triacylglycerols need to be looked for or designed. The appearance of diacylglycerol oils and fats also tries to address these problems, since diacylglycerols are in the thermodynamically stable 1,3-diacylglycerol forms and do not provide 2-monoacylglycerols for absorption and re-esterification to blood triacyglycerols. In a way the industry is moving away from looking at fats and oils as just organoleptic enhancers, flavor and vitamin carriers, or emulsifiers. Instead, their roles in health, disease prevention, neural development, and memory functioning are being explored in the development of new nutraceuticals or supplements.

There have been two recent reviews on dietary fat and prevention of cardiovascular disease [24, 25]. The conclusions from almost 50 years of studies indicate that modification or reduction of dietary fat intake has little effect on total mortality, and eating a low-fat diet does not increase longevity. Only the most stringent diets achieve plasma cholesterol reductions that are smaller than those available from the use of statin drug therapy. Reduction or modification of dietary fat intake in trials of long duration shows only a small reduction in cardiovascular risk.

Palm oil and coronary heart disease

Dietary palm oil lowers the total blood cholesterol and "bad" LDL cholesterol but increases the "good" HDL cholesterol, effects that are accepted to be beneficial against cardiovascular diseases. Thus palm oil does not behave like a saturated fat, although it contains almost equal proportions of saturated and unsaturated fatty acids. All the nutritional data show that palm oil behaves like an unsaturated fat. Apart from differences in unsaturation, there is a considerable difference between palm oil and coconut oil (a well-known saturated fat) in the detailed molecular composition of the glycerides (tables 1–3). Furthermore, the main saturated fatty acid in palm oil, palmitic acid, is very different from myristic acid, which is present in butter (13%), coconut oil (18%), and palm kernel oil (16%) but is practically negligible (1%) in palm oil. The saturated fatty acids of palm oil consist of palmitic acid (44%) and stearic acid (5%), and the unsaturated fatty acids are oleic acid (39%) (monounsaturated) and linoleic acid (10%) (polyunsaturated). Notably, the monounsaturated and polyunsaturated acids constitute 87% of the total fatty acids at the 2-position, which condition enables only these fatty acids to be easily absorbed. As a result, dietary palm oil behaves like a monounsaturated oil, and nutritional studies have consistently confirmed this. There is now a paradigm shift to consider important differences in absorption of fatty acids and 2-monoacylglycerols resulting from the action of digestive enzymes on the triacylglycerols and not just the overall fatty acid composition of the fat. In contrast to palm oil, it is evident that the largely saturated 2-positional fatty acids in coconut and many animal fats account for their hypercholesterolemic properties.

A number of pre-1990 human feeding studies reported that palm oil diets produced a reduction of blood cholesterol values ranging from 7% to 38% [26–30]. Many later nutritional studies, specifically designed to evaluate palm oil, confirmed that the effects of palm oil on blood cholesterol and lipoprotein profiles are beneficial.

- A comparative study in young Australian adults showed that the total blood cholesterol, triglyceride, and LDL-cholesterol levels of those fed palm oil (palm olein) and olive oil were lower than those fed the usual Australian diet [31]. Young Australian adults fed palm oil diets had the same total blood cholesterol, triglycerides, and "good" HDL-cholesterol levels as those fed olive oil.
- A double-blind crossover study [32] showed that a palm olein-rich diet was identical to an oleic acid-rich diet. A *trans*-fatty acid-rich diet elevated total cholesterol, "bad" LDL-cholesterol, and lipoprotein (a) and depressed "good" HDL-cholesterol relative to diets rich in oleic, stearic, lauric, and myristic acids.
- A study on 51 Pakistani adults showed that those given palm oil-rich diets performed better than those given sunflower oil. Palm oil increased HDL-cholesterol and Apo-A1 levels. Hydrogenated cottonseed oil raised blood triglyceride and lipoprotein levels [33].
- A study by the Institute of Nutrition and Food Hygiene, Beijing, China compared the effects of palm oil, soybean oil, peanut oil, and animal lard [34]. Palm oil decreased total blood cholesterol and "bad" LDL cholesterol while increasing the level of "good" HDL cholesterol. Soybean oil and peanut oil had no effect on blood cholesterol, but lard increased cholesterol levels. Among hypercholesterolemic subjects, palm oil diets lowered the cholesterol levels.
- A study conducted on healthy Indian subjects [35] showed that palm olein and groundnut oil had comparable effects. Neither oil induced hypercholesterolemia. In the same project, plasma lipoprotein (a) was also measured. There was a highly significant 10% decrease in lipoprotein (a) during consumption of the palm oil-rich diet. Lipoprotein (a) is a reliable indicator of the risk of cardiovascular disease, and a 10% decrease is therefore positive.
- A Malaysian study [36] compared the effects of diets containing palm oil (olein), corn oil, and coconut oil on serum cholesterol. Coconut oil raised serum total cholesterol by more than 10%, whereas corn and palm oil diets reduced total cholesterol by 36% and 19%, respectively.
- A crossover feeding study showed that the blood levels of cholesterol, triglycerides, HDL cholesterol, and LDL cholesterol of subjects consuming palm olein and olive oil diets were comparable [37].
- The effects of palm olein and canola oil on plasma lipids were examined in double-blind experiments in healthy Australian adults. Palm oil performed better than canola oil in raising the "good" HDL cholesterol [38].
- A similar cholesterol-lowering effect of palm oil was observed in 110 students in Malaysia [39]. The study compared the effect of palm oil with that of soybean oil. Volunteers fed palm oil (olein) and soybean oil for five weeks, with a washout period in the sixth week, had comparable blood cholesterol levels. However, the blood triglycerides increased by 28% on the soybean oil diet, implying that soybean oil provides more calories than palm olein. This is in agreement with the discussion above that there the uptake of free polyunsaturated fatty acids is better than that of the long-chain saturated ones. In an animal study palm olein fed rats showed a depression of fat storage as compared to soybean oil or tallow, a consequence of differences in uptake of the dietary fats [40].

All existing evidence discussed above indicates that the impact of palm oil on blood lipids is more like that of a monounsaturated rather than a saturated oil, making palm oil resemble olive oil. There appear to be a number of explanations.

Hayes and coworkers [41] demonstrated, in monkeys, that dietary myristic acid (14:0) and palmitic acid (16:0) have very different effects on cholesterol metabolism, myristic acid being strongly cholesterolemic (table 5). This effect was first noted in humans in 1965 but was subsequently largely ignored. Hayes and Khosla [42] advanced a hypothesis to explain the differing effects of dietary fatty acids on plasma total cholesterol reported in the literature over three decades. It was proposed that linoleic acid (18:2 *n*-6) up-regulates LDL receptors (i.e., permits full activity), allowing lipoprotein cholesterol to be cleared from plasma, whereas myristic acid (14:0) down-regulates the receptors (i.e., lowers receptor activity), resulting in a rise in LDL cholesterol; and that lauric acid (12:0) and palmitic acid (16:0) are equal and neutral in normocholesterolemic individuals and the requirement for 18:2 depends on the amount of 14:0 present. In diets that provide more than 5% to 6% of their energy as 18:2, fatty acids of any kind (except 14:0) have minimal effects. In diets that provide between 3% and 6.5% of their energy as 18:2, 14:0 is the only fatty acid to increase plasma LDL cholesterol, whereas in diets that provide less than 3% of their energy as 18:2,

TABLE 5. Fatty acid composition of palm oil and its effects on blood cholesterol[a]

Fatty acid	Composition (%)	Effects on blood cholesterol
Lauric (12:0)	0.2	Negative or neutral
Myristic (14:0)	1.1	Negative
Palmitic (16:0)	44.3	Neutral or slightly negative
Stearic (18:0)	4.6	Neutral
Oleic (18:1)	39.0	Positive
Linoleic (18:2)	10.5	Positive
Others (16:1,18:3)	0.3	Positive
Total in palm oil	100.0	Positive

a. Palm oil and palm olein contain very insignificant amounts of cholesterol-elevating saturated fatty acids (12:0 and 14:0); negative means cholesterol-raising.

myristic acid (14:0) is highly hypercholesterolemic but palmitic acid only moderately so. These interactions may be further modified by the quantity of cholesterol in the diet (at increasing levels, the sensitivity to saturated fatty acid may be greater) and by the initial concentration of plasma total cholesterol. Subjects who are already hypercholesterolemic may be more sensitive because their LDL receptors are saturated or down-regulated. If we derive as much as 30% of our energy from palm oil, the energy from linoleic acid should be more than 3%. Therefore, the effects of the main saturated fatty acid, palmitic acid, from palm oil would be almost neutral, and this was offered as an explanation of the cholesterol-lowering effects of palm oil, as discussed above. The benefits of having a *trans*-free fat cannot be overemphasized, as sufficient data have documented the dangers of *trans* fatty acids from partially hydrogenated fats [43–47].

As discussed in earlier sections, because of the specific action of pancreatic lipase enzymes, the position of the saturated and unsaturated fatty acid chains in a triacylglycerol backbone of the fat molecule determines which fatty acids are preferentially absorbed and subsequently their elevating or reducing effects on the cholesterol level in the blood [3, 4, 6, 10–13, 23, 48]. The highly structured triacylglycerols of palm oil with predominant unsaturation at the 2 position lead to these "unexpected" good properties. In palm oil, 87% of the fatty acids found in position 2 of the triglyceride molecule are unsaturated [4–9], whereas the saturated acids mainly occupy positions 1 and 3 (tables 1 and 2). This is the likely explanation why palm oil is not cholesterol elevating and possesses other associated beneficial properties.

There are also many beneficial properties of dietary palm oil. Blood clotting can be induced by injury to the blood vessel wall and the alteration (by diet) in the aggregating properties of blood platelets. Several studies are summarized below:

- Hornstra [49] in the Netherlands first demonstrated that palm oil has an anti-clotting effect, and is as antithrombotic as the highly unsaturated sunflower seed oil.
- A human study [50, 51] showed that tocotrienols (from palm oil) supplementation can reduce restenosis of patients with carotid atherosclerosis.
- Tocopherol and its relative, tocotrienol in palm oil, inhibit human platelets from "sticking" to each other. Evidence [52–54] showed that a palm oil diet either increases the production of prostacyclin which inhibits blood-clotting or decreases the formation of thromboxane which induces blood-clotting. Thus, scientific evidence indicates that the palm oil diet is no less antithrombotic than a diet based on polyunsaturated oil.

Palm oil does not promote the formation of plaques in the arteries. By feeding diets high in cholesterol along with certain saturated fats, such as milk fat, tallow, and coconut oil, atherosclerosis can be produced in rabbits, quail, pigs, and monkeys. Studies were conducted on rabbits to test the effect of palm oil on atherosclerosis [49, 55]. After the rabbits had been fed for 18 months, palm oil and sunflower oil diets caused the lowest degree of atherosclerosis in comparison with fish oil, linseed oil, and olive oil. Using the rabbit model, the effects of palm oil were compared with those of hydrogenated coconut oil, cottonseed oil, hydrogenated cottonseed oil, and an American experimental fat blend containing a mixture of butterfat, tallow, lard, shortening, salad oil, peanut oil, and corn oil. Rabbits fed coconut oil had the most atherosclerotic lesions, whereas in rabbits fed palm oil the number of lesions was no different from that in rabbits fed other oils.

Tocopherols, tocotrienols, and carotenoids

Refined palm oil, as used in foods, is a rich source of vitamin E and related compounds, such as tocotrienols. Mildly refined palm oil is also a rich source of these compounds, as well as of carotenoids. Tocopherols and tocotrienols are natural antioxidants [1, 2, 56–58] and protect the oil from oxidation. Being lipid soluble, they also have a protective role in vivo, especially to retard the oxidation of polyunsaturated acids. Animal experiments have shown that tocotrienols inhibit the enzyme HMGCoA reductase and consequently the synthesis of cholesterol [59, 60].

The tocopherols and tocotrienols capture and destroy damaging oxy free radicals that have been suggested to play a role in cellular aging, atherosclerosis, and cancer [50, 61–63]. Laboratory experiments on isolated rat hearts have shown that a tocopherol/tocotrienol concentrate from palm oil is more efficient than α-tocopherol in protecting the heart against the oxidative injury usually associated with postsurgical flow of fresh blood into the affected organ [64–67]. When the same tocopherol/tocotrienol concentrate was used in a controlled clinical trial to treat patients with vascular disorders that limited the flow of blood, the test subjects showed a significant increase in walking distance before onset of pain, as compared with the groups given aspirin or a placebo. A measure of oxidation of their blood lipids also showed significant reduction. The natural antioxidants protect LDLs from oxidation. LDLs are involved in the formation of atherosclerotic lesions, which may be exacerbated when the unsaturated fatty acid components in LDL have become oxidized.

In a recent cross-cultural epidemiologic study, the amount of vitamin E in plasma showed a strong inverse correlation with age-specific mortality from coronary heart disease. The plasma level of vitamin

E appeared to be more important than total plasma cholesterol in explaining cross-cultural differences in mortality from coronary heart disease [68]. In a paper on lipid peroxidation in skeletal muscle induced by exercise, the authors concluded that there was substantial protection against protein oxidation induced during resting as well as during exercise, by supplementing with various isomers, such as α-tocopherol and α-, β-, γ-, and δ-tocotrienols [69].

Among the tocotrienols that consist of α-, β-, γ-, and δ-analogues, δ-tocotrienol is the most potent antioxidant [56, 58]. It has been shown to be effective in inhibiting breast and liver cancer cells [56, 70–72]. Furthermore, this antioxidant has been proven to prevent oxidation of protein and lipids after strenuous bouts of exercise, making it useful for athletes, joggers, and bodybuilders. Unlike α-tocopherol, tocotrienols are not accumulated in the liver and appear to benefit the epidermis or skin [73, 74].

In parts of West Africa and Brazil, unrefined palm oil containing carotenoids is a traditional food that is recognized for its healthful aspects, including use as an ointment. However, unrefined palm oil is not widely available as a commercial product elsewhere. The main component of its carotenoids is β-carotene, which is a precursor of vitamin A. Presently mildly refined red palm oil is commercially available [17, 18, 20, 23].

Conclusions

Palm oil should be the preferred choice of food manufacturers and consumers for the following reasons.

Palm oil provides desirable oxidative stability, texture, and flavor characteristics. Because it is very stable toward free radical-induced oxidation, the formation of harmful oxidized products during processing and cooking is negligible as compared with that of polyunsaturated oils. Products incorporating naturally *trans*-free palm oil directly or as blends will have a long shelf life and other desirable properties.

The supply of genetic modification-free palm oil will be assured for a long time at economic prices because oil palm is a perennial crop with unparalleled productivity.

The belief that palm oil should be classified nutritionally with saturated fats is untrue. The fact is that palm oil behaves like an unsaturated oil such as olive oil. As a naturally structured oil, the 2-positional fatty acids which are easily absorbed are mainly monounsaturated but only 13% saturated. Furthermore, the saturated fatty acids consist of palmitic acid and stearic acid, which have been shown to have a relatively neutral effect on blood cholesterol elevation. Palm oil is as good as if not better than olive oil, especially with regard to the reduced tendency of blood to clot and the lower uptake of fatty acids. The lower uptake of palm fatty acids in comparison to those from polyunsaturated oils allows for the reduction of blood triacylglycerols and adipose deposits.

There are many nutritional qualities and benefits of the food use of palm oil. The dual LDL cholesterol-lowering and HDL cholesterol-raising effects are beneficial to the heart. Palm oil diets also improve levels of lipoprotein (a) and apo-A1. Mild processing of virgin palm oil provides oils with high carotenes, antioxidant tocopherols, and tocotrienols. These compounds have also been shown to be powerful antioxidants and potential mediators of cellular functions. They can be antithrombotic, cause an increase in the prostacyclin/thromboxane ratio, reduce restenosis, and inhibit HMG-CoA-reductase (thus reducing cholesterol biosynthesis).

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