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REVIEW

Fractionated palm oils: emerging roles in the food industry and possible cardiovascular effects

Birsen Yılmaz[a*] and Duygu Ağagündüz[b]

[a]Department of Nutrition and Dietetics, Gazi University, Ankara, Turkey; [b] Nutrition and Dietetics, Gazi University, Ankara, Turkey

ABSTRACT
The public health debate about fats and human health has been ongoing for a long time. Specifically, the fat types commonly used in the food industry and the techniques used in extracting them are remarkable in terms of human health. Among these, palm oil, which is mainly associated with cardiovascular disease (CVD), is a vegetable oil type that is widely used in the food industry. Moreover, the fractionation of palm oil has become quite common in the food industry when compared to other culinary oils and fats. Fractional crystallization, which has been recently regarded as an alternative to hydrogenization and interesterification methods, has become more popular in edible oil technology, even though it is an ancient method. The main fractions of palm oil are palm olein and palm stearin. Palm oil fractions, which have some pros and cons, are used in edible oils, such as margarine/shortening, as well as bread and cake-like pastry production. Since the fatty acid composition of palm oil, palm kernel oil, and their fractions is different, each type of oil needs to be evaluated separately with regards to their CVD effects and food preparation applications. However, the effects of the fractionation method and the fractional palm oil produced on health are controversial in the literature. In this review, the use of palm oil produced via the fractional crystallization method in the food industry and its potential CVD effects were evaluated.

KEYWORDS
Palm oil; palm olein; fractionation; food industry; cardiovascular disease; health

Introduction

Fats are macronutrients that have many physiological functions, in addition to being an important part of the human diet (Akoh 2002). Over the years, significant changes have occurred in the fat consumption and preferred fat types of people (Shan et al. 2019). In a population study between 1999 and 2016, it was demonstrated that the fat intake of individuals had increased (from 32.0% to 33.2%) significantly over the years, and this increase was particularly related to polyunsaturated fatty acids (PUFAs; from 7.58% to 8.23%), while saturated fatty acids (SFA; from 11.5% to 11.9%) continued to be consumed in high amounts (Shan et al. 2019).

The impact of fats on human health and the environment has always been a question of debate. Specifically, the fat types commonly used (e.g., margarine, butter, shortening, palm oil, some vegetable oils) in the food industry are remarkable in terms of human health (Valenzuela and Morgado 1999). Among these, palm oil is a type of vegetable oil that is widely used in the food industry in things such as cooking, spreads, confectionary fats, ice cream, emulsifiers, and margarines, because of its neutral taste, texture, and functionality in plenty of products, and therefore, it is very common in the diet (Mancini et al. 2015). Palm oil is found in many products, such as bakery products, frozen meals, peanut butter, snacks, soups, chips, chocolate, etc. (Mancini et al. 2015). However, some hypotheses have suggested that palm oil is associated with human health, especially cardiovascular diseases (CVDs), and that it has negative effects on the environment (Marangoni et al. 2017). While in some studies it has been suggested that the consumption of palm oil increases low-density lipoprotein cholesterol (LDL-C) more when compared to other vegetable oils, due to its saturated fat content (Sun et al. 2015; Gesteiro, Galera-Gordo, and Gonzalez-Gross 2018), other studies have not supported this view (Ismail et al. 2018; Wang et al. 2019). Supporting this, a comprehensive study including 23 countries showed that increased palm oil consumption has been associated with higher ischemic heart disease mortality rates in developing countries. (Chen et al. 2011). Moreover, Sun et al. (2015) compared the effects of palm oil con blood lipids with other vegetable oils using data from clinical trials and noted that palm oil significantly increased LDL-C (0.24 mmol/L) when compared with vegetable oils that were low in saturated fat (Sun et al. 2015). On the other hand, a recent meta-analysis reported that palm oil consumption had no noteworthy impact on LDL-C (Wang et al. 2019).

In addition to the types of oil, fat production techniques/modifications (e.g., partially or fully hydrogenation and interesterification) are frequently associated with health (Valenzuela and Morgado 1999). Modification techniques

CONTACT Duygu Ağagündüz duygu_turkozu@ymail.com Nutrition and Dietetics, Gazi University, Ankara, Turkey
*Present address: Department of Nutrition and Dietetics, Çukurova University, Adana, Turkey.

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commonly used in the edible oil industry are hydrogenation, interesterification, and fractionation (Kellens et al. 2007). Hydrogenization is a technique that has become rarely used due to its negative effects on human health, especially CVD risks, caused by trans-fatty acids released during fat modification, as well as its harmful impact on the environment due to the use of nickel catalysts (Kayahan 2002; Timms 2005). It was reported that there is a need for long-term evidence-based data on the subsequent effects on the health of the interesterification procedure, which has substantially replaced hydrogenization in the food industry (Mills, Hall, and Berry 2017). Fractional crystallization, which has been regarded as an alternative to the hydrogenization and interesterification methods, has become more popular in edible oil technology although it is an old method. Fractional fractionation of palm oil, which is mainly associated with CVD, is very common in the food industry (Kellens et al. 2007; Wang et al. 2019). However, evidence-based data on the effects of this method and of the fractional palm oil produced using this method on human health are almost non-existent.

In this review, the use of palm oil produced via the fractional crystallization method in the food industry and its potential CVD effects were evaluated.

Fat modification technologies in the food industry

Changes in the preferences of fat consumption of people have led to the emergence of different food matrices and innovations in the food industry. On the other hand, due to the high prices of butter in Europe in the mid-19th century, researchers started to design studies on fats that could replace butter. In 1869, a butter substitute was produced by French chemist Hippolyte Mège-Mouriès and was accepted as the first in this field (Ghotra, Dyal, and Narine 2002). In the beginning, lard was used in substitute oil production, and toward the end of the 19th century, hydrogenation studies continued to be conducted on oils such as cottonseed oil, corn oil, soy oil, coconut oil, palm oil, and palm kernel oil, as well as on fats and several oils (O'brien 2008). Subsequently, in 1903, Norman patented the hydrogenation of oils and fatty acids in liquid phase (O'brien 2008). Hippolyte Mège-Mouriès became the pioneer of fractional crystallization, one of the most ancient fat modification procedures, with the method he developed (Timms 2005). Furthermore, Holde and Stange reported, in 1901, that they obtained small amounts of solid triacylglycerols (TAGs) (mainly oleodipalmitin) by cooling oil down to −40 °C in ether solution (Holde 1901). Moreover, the use of low-temperature fractional crystallization for the separation of TAGs was also reported in the literature (Holde 1901). These developments, which occurred in the 19th and 20th centuries, formed the basis of modern fractionation methods used in the following years and the edible oil industry (Timms 2005).

Modification procedures frequently used in the edible oil industry include hydrogenation, interesterification (chemical and enzymatic), and fractionation (Kellens et al. 2007). As a result of the interesterification procedure, which has substantially replaced the hydrogenization that is frequently associated with an increased risk of trans fatty acid, there have been some concerns by consumers due to chemical use. Especially for the chemical interesterification process, some chemicals, such as sodium methoxide, sodium-potassium alloy, and sodium alcoholate, are used as a catalyst (Xu et al. 2006). Furthermore, little is known, based on the evidence, about the effects of the products obtained using this method on human health and metabolism (Mills, Hall, and Berry 2017). On the other hand, dietary trans fatty acids are mainly taken from industrial sources (partial hydrogenation of edible fats containing unsaturated fatty acids, such as shortening and hard margarine, etc.) and secondarily by consuming edible tissues of ruminant animals (formed by the bacterial transformation in the rumen of a ruminant). In a study investigating the trans fatty acid intakes and dietary sources in 29 countries, it was reported that the trans fatty acid intake in 7 countries was >1% of the total energy intake (Wanders, Zock, and Brouwer 2017). The World Health Organization (WHO 2018) recommends that trans fatty acid intake should be limited to less than <1% of the total energy intake. In addition to the negative health effects on CVDs, which have been well-documented in the literature, trans fat intake may also increase the risk factors of many chronic diseases, such as diabetes, obesity, insulin resistance, systemic inflammation, endothelial dysfunction, and adiposity (Teegala, Willett, and Mozaffarian 2009). In the Nurses' Health Study, which is the largest prospective study on trans fatty acid intake and diabetes, 84,204 women aged 34–59 years with no diabetes, CVDs, or cancer were followed-up, and 14 years later, it was reported that total fat and monounsaturated fatty acid (MUFA) intake were not associated with the risk of type 2 diabetes, while PUFA reduced the risk, and trans fatty acids increased the risk (Salmerón et al. 2001).

Since it is not obligatory to specify the method used on the labels of food produced using the interesterification method, it becomes more difficult to analyze the amount of consumed interesterified fat, and therefore, its health effects. Due to its effects on human and environmental health, fractional crystallization, which is considered to be more sustainable as an alternative to the hydrogenization and interesterification processes, is becoming more popular day by day (Calliauw, Gibon, and De Greyt 2007). Fractional crystallization involves changing the physicochemical features of lipids by physically separating TAGs by selective crystallization and filtration (Calliauw, Gibon, and De Greyt 2007). This procedure is characterized by the separation of the liquid phase and the solid phase after crystallizing the fat material. The principle of this procedure is based on differences in the solubility of solid TAGs in the liquid phase, depending on the molecular weights and unsaturation degrees of TAGs (Kayahan 2002; Kellens et al. 2007). The fractionation process is mostly focused on variations in the constituent TAG melting points in an oil/fat. The resulting products are a liquid phase and a solid phase that are called olein and stearin, respectively (Omar et al. 2015). While the

Table 1. Positional distribution of fatty acids in the triacylglycerol molecule in some oils (mol/100 mol total fatty acids).

Type of oil	Fatty acids			Reference
	SFA	MUFA	PUFA	
Human milk				(Berry and Sanders 2005)
sn-1 and *sn*-3	31	46	11	
sn-2	61	13	7	
Olive oil				(Ong and Goh 2002)
sn-1	15.7	72.7	10.4	
sn-2	1.4	83.6	14.8	
sn-3	21.1	74.7	6.4	
Palm oil				(Berry and Sanders 2005)
sn-1 and *sn*-3	50.0	41.0	7.0	
sn-2	8.0	71.0	19.0	
Palm kernel oil				(Teh et al. 2018)
sn-1 and *sn*-3	90.2	8.8	1.0	
sn-2	75.6	23.2	1.2	
Palm olein IV56				(Teh et al. 2016)
sn-1 and *sn*-3	67.1	26.8	6.1	
sn-2	10.4	65.8	23.8	
Palm olein IV64				(Teh et al. 2016)
sn-1 and *sn*-3	60.7	34.5	4.8	
sn-2	8.5	63.9	27.6	
Palm olein IV72				(Teh et al. 2016)
sn-1 and *sn*-3	51.3	41.9	6.8	
sn-2	4.3	67.1	28.6	

SFA: saturated fatty acid, MUFA: Monounsaturated fatty acid, PUFA: Polyunsaturated fatty acid.

performance of the stearin fraction depends on the separation step as well as the crystallization step, the performance of the olein fraction depends on the crystallization (Huey, Let, and Beng 2015). It has been shown that the chemical composition, such as TAG, diacylglycerols, free fatty acid, and additives, affect palm oil crystallization (Omar et al. 2015). The fractionation process is cheap, safe, and eco-friendly by comparison with other edible oil processing technologies. It is also simple, since it involves the controlled crystallization of the melted oil accompanied by the physical separation of the phases of solids and liquids (Calliauw, Gibon, and De Greyt 2007).

Fats that are solid at room temperature usually contain many triglyceride mixtures with different melting points. These components can be separated from one another by a fraction. As a result of the fractionation procedure, fractions with significantly different physical features can be obtained. Fats obtained in this procedure can be separated again into fractions (double fractionation), and different types of fat could be obtained (Campbell et al. 2006).

Industrially, the 3 basic methods used to produce crystals from fats are detergent fractionation, solvent fractionation, and dry fractionation (Kayahan 2002; Kellens et al. 2007). Dry fractionation is a cheaper and simpler technique when compared to the other methods. Moreover, since there is no possibility of chemical use or waste formation in this technique, it is among the dominant methods used in edible oil technologies (Timms 2005). Among edible oils, palm oil is the most fractionated oil, and the majority is fractionated through dry fractionation (Omar et al. 2015). On the other hand, it is not possible to separate all of the liquid from the solid phase in dry fractionation. When compared to dry fractionation, solvent fractionation is more effective in reducing liquid oil entrapment, thus, increasing the oil yield and the hardness of the solid fraction. However, it has lost its appeal due to its cost and health risks, like detergent fractionation (Huey, Let, and Beng 2015). In addition to these disadvantages, there may be detergent contamination of the end products in detergent fractionation (Kellens et al. 2007). Because of the disadvantages mentioned above, dry fractionation is commonly used in the edible oil industry.

Palm oil fractionation and the food industry

Palm oil contains almost the same amount of SFAs (mainly palmitic acid 44–45%) and unsaturated fatty acids (oleic acid 39–40%, and linoleic acid 10–11%), and it is extracted from the fruit of *Elaeis guineensis* (Akoh 2002; Voon et al. 2019). The high-quality palm oil used in the edible oil industry contains a large number of neutral TAGs (95%) and low free fatty acids (less than 0.5%), low impurity content, and good bleaching (Mancini et al. 2015).

A triglyceride molecule consists of a glycerol moiety esterified with 3 fatty acids. The fatty acids in each TAG molecule may contain a mixture of different fatty acids, as well as all 3 of the same fatty acids. Although the position of the fatty acids in the TAG molecule was not considered at first, it is obvious that it has an important place in terms of plasma lipids and CVDs (Berry 2009). Palm oil contains approximately 12 major TAGs; however, a significant portion (10–15%) of saturated acyl esters in its composition is in the second (*sn*-2) position (Akoh 2002) (Table 1). It was observed that the *sn*-1 and *sn*-3 positions were saturated throughout the TAG molecule. Palmitic acid and stearic acid attach to the *sn*-1 and *sn*-3 positions, while oleic acid and linoleic acid attach to the *sn-2* position (Marangoni et al. 2017) (Figure 1). It is known that the saturation in the *sn*-2 position has a higher cholesterol-increasing effect, and therefore, it could affect nutrient properties (Berry and Sanders 2005). On the other hand, it is known that palmitic acid increases total cholesterol and LDL-C levels when compared with PUFA, MUFA, and carbohydrates. Although palm oil contains a high level of palmitic acid (about 45%), it does not increase cholesterol concentrations to the prescribed degree because of the position of palmitic acid in the palm oil TAG molecule (Berry 2009).

There are two different types of oil that can be extracted from the palm fruit. Palm oil is extracted from the mesocarp section of the palm fruit, while palm kernel oil is extracted from the palm kernel (Figure 2). While the major fatty acids of palm oil are palmitic acid and oleic acid, those of the palm kernel oil are lauric acid and myristic acid (Padial-Jaudenes et al. 2020). Palm kernel oil has a composition similar to coconut oil in terms of its high in medium-chain saturated fatty acids (approximately >80%) (USDA 2020).

Due to the low linoleic acid content in palm oil, it is more stable against oxidative degradation in food preparation processes (Foster, Williamson, and Lunn 2009). Palm oil has a semi-solid form at room temperature (25–30 °C) due to its high saturated fatty acid content. When palm olein is fractionated by crystallization, liquid fractions that are clear and colorless at room temperature are obtained, and when palm stearin is fractionated in solid form, oils

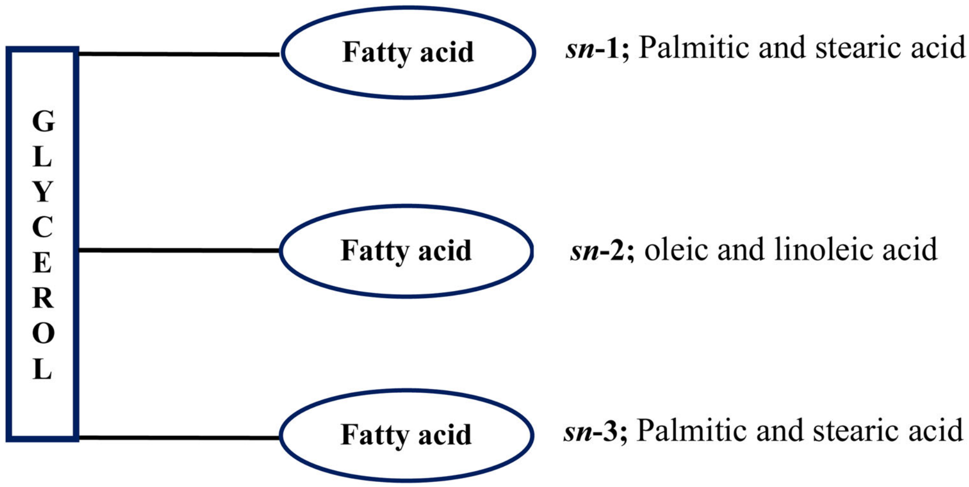

Figure 1. *Sn* positions of fatty acids in the triacylglycerol molecule of palm oil.

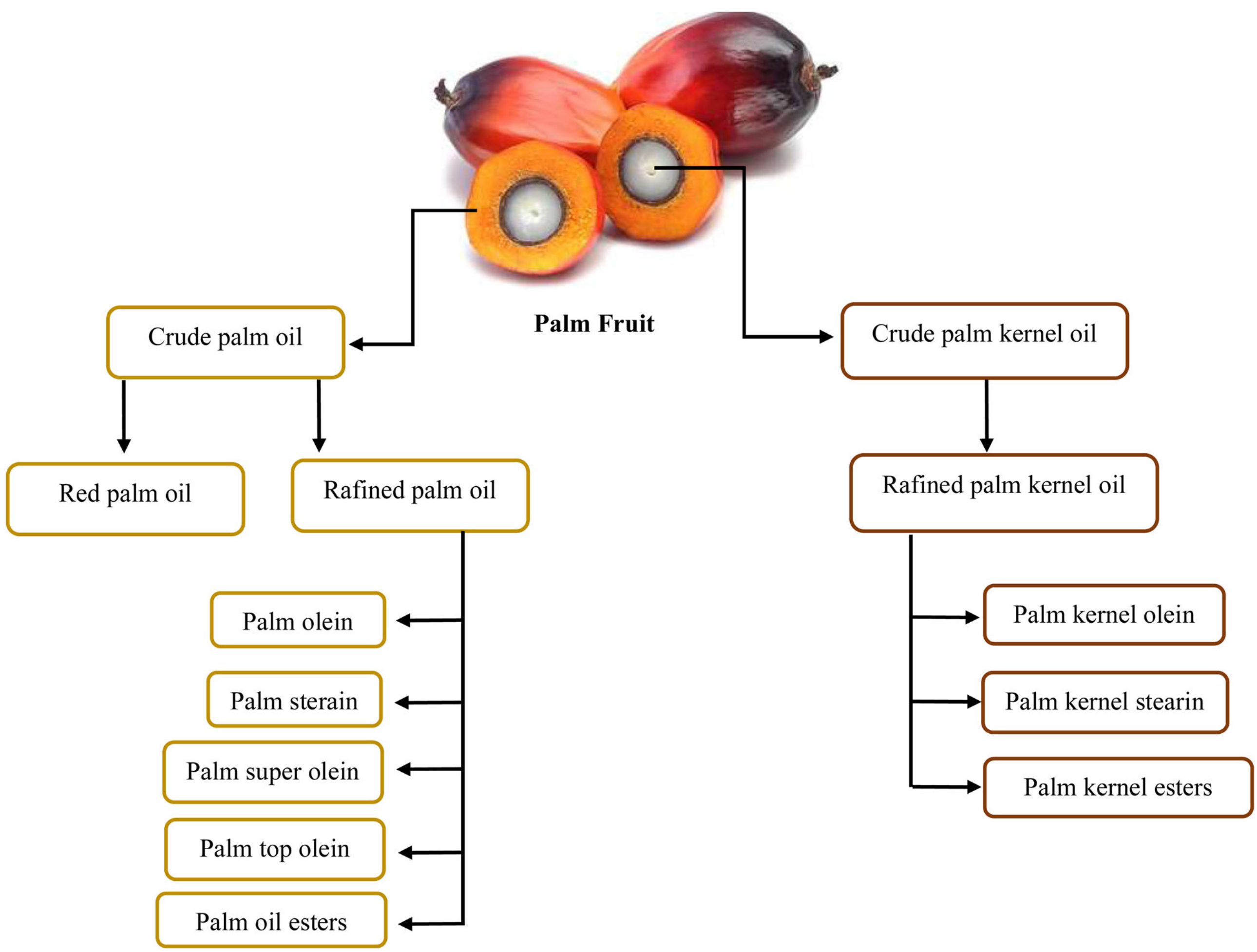

Figure 2. Fractional oil types obtained from palm fruit.

with different features from those of palm oil at room temperature are obtained. Palm super olein is produced by further fractionating palm olein, and the oleic and linoleic fatty acid content in this oil is higher than that in palm olein. Palm top olein is produced by further fractionating palm super olein. As the fractionation procedures proceed, the iodine value of the oil increases (Council 1989; Akoh 2002).

Palm oil fractions are often used as the main base stocks in producing margarine and shortenings. Palm stearin and palm olein blends can also be used to produce zero-trans margarine fat via enzymatic transesterification (Sellami et al. 2012). Palm stearin is a solid fraction that is physically derived by the fractionation of palm oil without any modification process (Farajzadeh Alan et al. 2019). Palm stearin fraction is generally used in the food industry in bread and cake-like pastry production (Foster, Williamson, and Lunn 2009). Unfortunately, palm stearin is not used directly for edible functions because of its high melting point and low

Table 2. Fatty acid composition of palm oil, palm kernel oil, and palm oil's derivates.

Type of oil	Main fatty acids	SFAs (g/100 g)	MUFAs (g/100 g)	PUFAs (g/100 g)			Reference
				Total	n-6	n-3	
Palm oil	Palmitic acid Oleic acid Linoleic acid	47.8	37.1	10.4	10.1	0.3	(Foster, Williamson, and Lunn 2009)
Palm kernel oil	Lauric acid Myristic acid Oleic acid	81.5	11.4	1.6	1.6	0	(USDA 2020)
Palm olein	Palmitic acid Oleic acid Linoleic acid	45	42	11	11	0	(Campbell et al. 2006)
Palm super olein	Oleic acid Palmitic acid Linoleic acid	36.5	46.3	13.6	13	0.6	(T.C. Tarım ve Orman Bakanlığı 2015)
Palm stearin	Palmitic acid Oleic acid	68	26	7	6.5	0.5	(T.C. Tarım ve Orman Bakanlığı 2015)

SFA: saturated fatty acid, MUFA: Monounsaturated fatty acid, PUFA: Polyunsaturated fatty acid

plasticity (Farajzadeh Alan et al. 2019). Hence, detailed food consumption records of individuals regarding foods rich in palm stearin should be compiled to attain information and discuss the amount of consumption, and associate it with health effects. Moreover, evidence-based knowledge of fractional palm oils, except for palm olein, on human health is almost non-existent.

Since the fatty acid composition of palm oil, palm kernel oil, and their fractions is different, each type of oil needs to be considered and analyzed separately (Table 2). Palm olein, one of the main fractions of palm oil is used as culinary oil in the household, while palm stearin is used in margarine and shortening production (Ong and Goh 2002). Palm oil is one the most produced and consumed edible oils worldwide (Ismail et al. 2020). On the other hand, unrefined palm oil is considered and consumed as a traditional food in households in some parts of West Africa and Brazil. However, commercial palm olein is widely used in southeast Asia and Sub-Saharan Africa (Council 1989; Ong and Goh 2002).

Palm oil fractionation and cardiovascular effects

While the use of palm oil in the food industry and other fields is increasing day by day, it also causes some health concerns. Although the ratio of SFA to MUFA and PUFA is nutritionally suitable (approximately 1:1), its negative effects on blood lipids (e.g., undesired increase in TAG, total and LDL-C levels, and/or decreased HDL-C levels) are continuously discussed due to its high SFA content (Marangoni et al. 2017). On the other hand, when analyzed, the literature demonstrated that there is no clear consensus on some oil types containing SFAs and CVD to date (Harcombe, Baker, and Davies 2017). Likewise, a comprehensive review including large meta-analyses has also reported that reducing SFAs did not have any beneficial effect on mortality and CVDs. Although it was reported that SFAs increase large LDL-C particles, there was a weak positive relationship found between CVD risk and these particles (Astrup et al. 2020).

Palm oil is one of the most fractionated oils when compared to other oils and fats (Gunstone 2006). The first analyses associated with palm olein and blood lipids in the literature were conducted in the 1990s, and studies with different hypotheses continue to be conducted today (Ng et al. 1991; Boon et al. 2013; Lv et al. 2018). Studies generally focus on palm olein and parameters associated with CVDs, inflammatory markers, and adipokines (Teng et al. 2011; Voon et al. 2011; Lv et al. 2018).

In the literature analyzing the relationship between palm fractions and health, palm olein fraction has often been analyzed and compared to other oil types (Choudhury, Tan, and Truswell 1995; Reddy and Sesikaran 1995; Truswell, Choudhury, and Roberts 1999; Sun et al. 2018). Hence, the present study classified and categorized the studies that have conducted on palm olein and different oil types into 3 different headings to compare them with fats and oils rich in PUFAs, MUFAs, and SFAs. Since more than 2 types of fat were compared in some studies, they were categorized into the most suitable title.

Palm olein and PUFA rich oils

Compared to SFAs, PUFAs are thought to have more positive effects, such as lower total and LDL-C, on heart health. Although these effects are seen in the diet when PUFA is given instead of SFA, the overall health effects of PUFAs are still unknown (DiNicolantonio and O'Keefe 2018). Although randomized-controlled trials on long-chain omega-3 PUFAs have generally been reported with unbiased findings, their use in the prevention of atherosclerotic CVD has been supported by some studies. There has been a long debate about the possible adverse consequences of a high intake of omega-6 PUFAs, but this hypothesis has not been confirmed by prospective observational studies or randomized controlled trials. On the other hand, it is still controversial whether PUFAs are pro or anti-inflammatory (Schulze et al. 2020; Shramko et al. 2020).

In a study conducted with healthy volunteers, the effects of diets containing different types of fat on serum cholesterol were compared. While coconut oil increased serum total cholesterol by >10%, corn oil and palm olein decreased serum total cholesterol by 36% and 19%, respectively (Ng et al. 1991). In another study conducted with adolescents, the plasma lipid profile was analyzed by changing the type of dietary oils (palm olein and soybean oil). In the first 5 weeks, the participants used palm olein as a culinary oil, and they used soybean oil for 5 weeks after a washout period of 6 weeks. While there was no significant difference between these 2 oils in terms of plasma total cholesterol, LDL-C, or high-density lipoprotein cholesterol (HDL-C), soybean oil caused a significant increase (47%) in the plasma triglycerides when compared to palm olein. On the other hand, palm olein significantly increased the apolipoprotein A-I (11%) and apolipoprotein B (9%) concentrations, regardless of the effects on plasma lipid levels (Marzuki et al. 1991). In a recent single-blind randomized study, 3 different types of oil, i.e., soybean oil, palm olein, and cocoa butter, were compared and the proportion of energy obtained from the macronutrients of each group was adjusted to be approximately 35% fat, 16% protein, and 49% carbohydrate. As a result of the 16-week study, it was reported that there was not a significant difference in CVD risk factors after dietary intervention using palm olein and that palm olein, which contains high levels of SFA, did not affect the lipid profiles, insulin resistance, liver or kidney functions, or especially, the oxidative stress level, considering the composition of the oil in the diet. In the study, it was underlined that the total number of participants in the 3 different groups might not have been sufficient and that dietary modifications might not affect CVD risk factors in theory (Lv et al. 2018). Unlike other studies, 43 hyperfibrinogenaemic volunteers participated in a randomized controlled single-blind study in which palm olein was compared to sunflower oil, as well as red palm olein.

The effects of these oil types on the lipids, hemostatic factors, and fibrin network characteristics of the individuals were analyzed. After giving products that contained sunflower oil to the individuals for 4 weeks, the participants were divided into 3 groups, and each group was given a different oil type for another 4 weeks (25 g/day). It was reported that consuming 25 g/day of palm olein regularly had a hypercholesterolaemic effect when compared to the other oil types, and that red palm olein, despite having a similar fatty acid pattern, did not produce such an effect (Scholtz et al. 2004).

The fact that the antioxidant content of the red palm olein was higher than that of palm olein might have produced these results. Moreover, since other studies were conducted with healthy, and especially, young individuals, it might not have been the right approach for a comparison across groups.

Palm olein and MUFA rich oils

The effects of dietary fats and oils on plasma lipid and lipoprotein levels have been studied for many years. While SFA has been shown to increase the level of total and LDL-C, MUFAs are considered to be low-risk for CVDs (DiNicolantonio and O'Keefe 2018). Ng et al. (1992) analyzed the effect of palm olein, olive oil, and coconut oil on serum cholesterol and lipoprotein profiles by organizing the diet of 33 normocholesterolemic participants according to different oil types. It was reported that palm olein and olive oil had a similar effect after 6 weeks (Ng et al. 1992). In another study conducted with 21 normocholesterolemic individuals, their diets were adjusted to contain 50% of fat as palm olein or olive oil, and after 30 days, no difference could be found between the 2 oil types on the blood lipid and lipoprotein profiles (Choudhury, Tan, and Truswell 1995). In a double-blind study conducted with healthy adults, the effect of palm olein and canola oil on plasma lipids was analyzed and it was observed that palm olein increased HDL-C by 10%, while canola oil did not produce such an effect (Truswell, Choudhury, and Roberts 1999).

The effect of these 2 oil types on blood lipids and platelet aggregation was analyzed by making several modifications to the daily dietary plans of healthy individuals (related to the oil type), in addition to the typical Indian diet. It was concluded that there was not a significant change in the plasma total cholesterol LDL-C or HDL-C fractions, or very-LDL-C (VLDL-C) levels in individuals that were given palm olein and peanut oil (groundnut oil), which is one of the oil types with high MUFA contents (MUFA >50%) (Reddy and Sesikaran 1995). In a double-blind study conducted by Sundram, Hayes, and Siru (1995), 23 healthy normocholesterolemic male volunteers were provided 3 different diets [i-oleic acid-rich diet, and canola oil; ii-palmitic acid-rich diet, and palm olein; and iii-American Heart Association (AHA) (Step I fat blend)], and their effects on blood lipids were analyzed. All of these diets were organized in a way that the energy obtained from fats would be approximately 31% and <200 mg cholesterol/day (Sundram, Hayes, and Siru 1995). Despite having organized specific fatty acids, when compared, these 3 diets demonstrated that there was no difference regarding the serum total cholesterol, VLDL-C, or LDL-C, while the HDL-C levels in the individuals increased after the AHA diet and LDL-C/HDL-C levels decreased significantly. Since the AHA Step I fat blend diet contains PUFA and SFA fatty acids, it was underlined that they were required to increase HDL-C (Sundram, Hayes, and Siru 1995). Sun et al. (2018) compared palm olein and olive oil in a randomized double-blind study conducted with 100 normocholesterolemic individuals. In their test diets, the energy ratio was adjusted to 30% for the oil and 60% for the fats in the diet from the oil type used. It was concluded that the consumption of a palm-olein-rich diet and olive oil-rich diet did not cause a significant change in body mass index, serum total cholesterol, LDL-C, HDL-C, TAG, apolipoprotein B, fasting glucose, or insulin concentration (Sun et al. 2018).

In a review, researchers focused on the estimated levels of serum cholesterol based on human studies, and the relationship between total fatty acid consumption and the *sn*-2 position in triglycerides (Teh et al. 2016). They concluded that fatty acids at the *s*-2 position appeared to influence cholesterol levels rather than the total fatty acids of the triglyceride. Therefore, it was concluded that the *sn*-2 position of TAGs caused the effects of different fat types on the serum cholesterol levels to be different (Teh et al. 2016). The fact that palm olein, despite having a high SFA content, affects the blood lipid profile similarly when compared to oils with high MUFA/PUFA content may be explained by the *sn*-2 position theory.

In a double-blind, randomized, 3×3 week crossover intervention study without a washout period, 3 oil types, i.e. palm olein, lard, and olive oil, were compared (Tholstrup, Hjerpsted, and Raff 2011). A portion of the fat in the diets of the individuals (approximately 17%) was adjusted to be obtained from these oil types. When compared to olive oil, it was found that the total cholesterol and LDL-C levels increased in the group that was given palm olein and lard, whereas there were no changes according to the oil type in terms of the plasma HDL-C, high-sensitivity C-reactive protein, plasminogen activator-1, insulin, or glucose concentration (Tholstrup, Hjerpsted, and Raff 2011).

Palm olein and SFA-rich oils

Although palm oil has a high SFA content, it has different effects on blood lipids when compared to other oil types with a high SFA content (such as coconut oil and lard) (Teng et al. 2011; Voon et al. 2011; Filippou et al. 2014). Hayes et al. (1991) reported that myristic acid (14:0) and palmitic acid (16:0) had different effects on cholesterol metabolism, and that myristic acid had a stronger cholesterolemic effect. Another fatty acid type that is thought to have a negative effect on cholesterol metabolism is lauric acid (12:0). Although myristic acid and lauric acid are found in low amounts in palm oil (1.1% and 0.2%, respectively), the effect of fatty acids that are found in high amounts in palm oil [palmitic acid (16:0), oleic acid (18:1)] on blood cholesterol has been either positive or neutral (Hayes et al. 1991). Similarly, in a study examining the effect of SFA on the plasma lipid profile, plasma homocysteine, and inflammatory markers, healthy individuals were given 3 different oil types, comprising palm olein, coconut oil, and myristic acid, and virgin olive oil. At the end of the study, no difference was found between the 3 diets in terms of plasma total homocysteine or the inflammatory markers (Voon et al. 2011).

In a single-blind study comparing 3 different oil types (palm olein, interesterified palm olein, and high oleic acid sunflower oil, the energy rate obtained from the fats in the diet was determined to be 20%. While the LDL-C level was lower in the group that was given high oleic acid sunflower oil when compared to the other 2 oil types, it was found that the plasma glucose was 8% lower in the interesterified palm olein group. No difference was found between these oil types in terms of the C-peptide levels. Postprandial lipemia may trigger the proinflammatory state that impairs insulin sensitivity and may lead to the progression of CVDs (Filippou et al. 2014).

The effect of different oil types (palm olein with high SFA content, lard, and olive oil) on postprandial lipemia, postprandial plasma glucose and insulin, proinflammatory cytokines, and leptin were analyzed (Teng et al. 2011). While palm olein and olive oil produced similar effects on postprandial lipemia, it was found that serum TAG concentrations were significantly lower after a meal enriched by lard when compared to the other oil types. Plasma glucose, insulin, adipocytokines, and leptin were not affected by the oil type used in the diet (Teng et al. 2011). It was thought that the positional distribution of fatty acids in the TAG molecule affected the metabolism of lipids (Teng et al. 2011). It was suggested that the structure of TAGs may explain why fats of animal origin were more atherogenic than palm oil in animal models (Kritchevsky and Tepper 1977). In other respects, human studies also showed that palmitic acid was better absorbed, and this situation positively affected plasma lipid levels, when found in the *sn*-2 position (like in human breast milk) when compared to the *sn*-1 and *sn*-3 positions. A randomized crossover design study conducted with healthy women and men showed that fats with a higher amount of palmitic acid in the *sn*-2 position decreased postprandial lipemia (Berry 2009; Sanders et al. 2011).

The positional distribution of fatty acids at the *sn*-2 position may play a role in postprandial lipemia. Therefore, the health effects of edible oil types may be associated with fatty acid distribution, and the *sn*-1, *sn*-2, and *sn*-3 positions. However, it should take into consideration that there is not enough information on the long-term health consequences of consuming oils that contain high levels of palmitic acid in the *sn*-2 position, the effects of the fatty acid saturation level, or the carbon chain length of fatty acids on this position.

Conclusion

Fractional crystallization, an alternative to other modification techniques of fats and oils, is becoming more popular day by day. One of the most fractionated oils is palm oil. Presently, there is growing public health concern related to palm oil and CVDs because of its nutritional composition. However, palm oils produced via the fractional crystallization method, such as palm olein and palm stearin, possess a wide range of usage in the food industry and have different nutritional values, especially the fatty acid composition. Therefore, when talking about the effects of palm oil on CVDs, the effects of its fractions should not be generalized. That is why the most striking result to emerge from this review was that palm oil fractions, especially palm olein, may have very different CVD effects. According to studies in the literature, it was reported that palm olein may not have a negative effect on blood lipids in healthy individuals with a normal body weight, similar to oils with a high MUFA content. Although the SFA content is high, it is difficult to explain this result, but the use of fractionation appears to be promising in terms of its effects on CVD, especially on blood lipids when compared to the non-fractionated form of palm oil. A possible explanation for this might be that studies have generally been conducted on healthy, normal weight, and young adults. A further study with more focus on individuals with chronic disease, obesity, older adults, or with any CVD risk is therefore suggested. Another possible explanation for this is the position of the fatty acids (the *sn*-2 theory). However, it should also be taken into account that it cannot only be explained by the *sn*-2 theory. Comprehensive, long-term, and randomized studies are required to understand the health effects of palm oil fractionation and its related mechanisms more clearly.

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Abbreviations

AHA	American Heart Association
BMI	Body mass index
CVD	Cardiovascular diseases
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
MUFA	Monounsaturated fatty acid
PUFA	Polyunsaturated fatty acids
SFA	Saturated fatty acids
TAG	Triacylglycerols
VLDL-C	Very low-density lipoprotein cholesterol levels

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