



Review article

Balancing functional and health benefits of food products formulated with palm oil as oil sources



N.S. Sulaiman^a, M.D. Sintang^a, S. Mantihal^a, H.M. Zaini^a, E. Munsu^a, H. Mamat^a, S. Kanagaratnam^b, M.H.A. Jahurul^{c,**}, W. Pindi^{a,*}

^a Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia

^b Malaysian Palm Oil Board, 6 Persiaran Institusi, Bandar Baru Bangi, 43000, Kajang, Selangor, Malaysia

^c Department of Agriculture, University of Arkansas, 1200 North University Dr., M/S 4913, Pine Bluff, AR 71601, United States

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ABSTRACT

Palm oil (PO) is widely utilised in the food industry and consumed in large quantities by humans. Owing to its bioactive components, such as fatty acids, carotenoids, vitamin E, and phenolic compounds, PO has been utilised for generations. However, public concern about their adverse effects on human health is growing. A literature search was conducted to identify fractionated palm oil processing techniques, proof of their health advantages, and potential food applications. Refined palm oil (RPO) is made from crude palm oil (CPO) and can be fractionated into palm olein (POI) and palm stearin (PS). Fractional crystallisation, dry fractionation, and solvent fractionation are the three basic fractionation procedures used in the PO industry. The composition of triacylglycerols and fatty acids in refined and fractionated palm oil and other vegetable oils is compared to elucidate the triacylglycerols and fatty acids that may be important in product development. It is well proven that RPO, POI, and PS extends the oil's shelf life in the food business. These oils have a more significant saturated fat content and antioxidant compounds than some vegetable oils, such as olive and coconut oils, making them more stable. Palm olein and stearin are also superior shortening agents and frying mediums for baking goods and meals. Furthermore, when ingested modestly daily, palm oils, especially RPO and POI, provide health benefits such as cardioprotective, antidiabetic, anti-inflammatory, and antithrombotic effects. Opportunities exist for fractionated palm oil to become a fat substitute; however, nutrition aspects need to be considered in further developing the market.

1. Introduction

Palm (*Elaeis guineensis*) has been widely grown for its oil-rich nuts and fruit in recent decades. It is both the world's oldest and fastest-growing fruit oil crop (Di Genova et al., 2018). Palm oil (PO) accounts for more than half of all vegetable fats and oils consumed (Gonzalez-Diaz et al., 2021). The world's leading and second largest producers of PO, Indonesia and Malaysia, produced more than 85% of the global PO supply (Absalome et al., 2020). As demand for PO applications develops, production is predicted to reach 240 million tonnes by 2050 (Sehgal and Sharma, 2021). Under specific chemical and mechanical conditions, crude palm oil (CPO) is extracted from the mesocarp of the fruits produced by the cultivars tenera D x P (Dura x Pisifera) (Gesteiro et al., 2019). Meanwhile, palm kernel oil (PKO) is derived from the oily, dull-white endosperm of

the palm fruit's seed (Azimah and Zaliha, 2018; Choudhary and Grover, 2019).

Fractionation of triacylglycerols (TAGs) is the most prevalent modification approach for enhancing PO utilization (Zhang et al., 2021). This type of fractionation increases the usefulness of oils and fats, allowing them to be used in more edible and non-edible applications. Edible oils and fats have been fractionated since the 19th century to supply feed-stocks for margarine, spreads, confectionery fats, emulsifiers, and shortenings, among other things (Choudhary and Grover, 2019). Refined palm oil (RPO) is usually split into two fractions: a liquid olein (POI) fraction with better cold stability and a solid stearin (PS) fraction with better melting properties (Hishamuddin et al., 2020).

RPO, POI, and PS are popular components in baking, processed meals, snacks, frozen foods, and chocolate due to their neutral taste, texture, and

* Corresponding author.

** Corresponding author.

E-mail addresses: akandam@uapb.edu (M.H.A. Jahurul), woly@ums.edu.my (W. Pindi).

practicality. RPO is one of the most extensively utilized oil by food makers. Not only because of its inexpensive cost, but also because of its unique properties, such as its high level of monounsaturated fatty acids and vitamin E, as well as its low content of polyunsaturated fatty acids (Dian et al., 2017). As a result, it is found in a lot of people's everyday meals (Mancini et al., 2015). However, according to the World Health Organization (WHO), eating a PO-rich diet on a daily basis may increase the risk of cardiovascular disease (WHO, 2003).

According to some assumptions, PO's high saturated fatty acid content is hazardous to customers' health (Kadandale et al., 2019). The "lipid hypothesis" introduced the concept that saturated fatty acids (SFAs) raises serum total cholesterol and LDL-C (Bier, 2016). High cholesterol levels cause coronary artery lesions, increasing the risk of cardiovascular disease (Ruiz-Núñez et al., 2016). SFAs such as palmitic acid (C16:0), myristic acid (C14:0), and lauric acid (C12:0) can impact plasma cholesterol levels by preventing cholesterol from being eliminated from the bloodstream and increasing circulating cholesterol resources through de novo biosynthesis (Gu and Yin, 2020; Agostoni et al., 2016).

However, there are conflicting and contradicting findings on the negative and positive health effects of PO use. Some studies link PO consumption to an increased risk of death from ischemic heart disease, whereas others showed a favorable result from PO consumption with no adverse health impacts (Hayes and Pronczuk, 2010; Sun et al., 2015). As a result, it's difficult to say whether PO is entirely healthful and safe to use in food products in terms of cardioprotection (Gesteiro et al., 2019). The current study examines refined palm oil and its fractionated components: palm olein and palm stearin, in terms of their fractionation method, potential applications in food, and health advantages.

2. Fractionation of palm oil

In tropical temperatures, PO is semi-solid and can be divided into two fractions: olein, which has a low melting point, and stearin, which has a high melting point (Figure 1). Fractional crystallization, which can be classified into dry and solvent fractionation, is used to separate oils and fats into two or more components (Table 1). The first stage of

fractionation is crystallization, which is followed by the separation of solid and liquid fractions (Hasibuan et al., 2021). In dry fractionation, the high melting point triglycerides are separated by cooling the oil mixture, and the products are obtained through filtration based on different melting points (Lu et al., 2021). Dry fractionation is favorable as the process is environmentally friendly, but it increases physicochemical parameters of PO derivatives such as melting point and iodine value (Nusantoro, 2009; Hashem et al., 2018). Meanwhile, solvents like acetone are frequently utilized in solvent fractionation to facilitate separation at low temperatures while maintaining good yield and purity (Kang et al., 2013). However, only a few research have looked at the impact of fractionation conditions, specifically the operating temperature, on the physicochemical qualities of the sub-products derived from PO fractionation.

2.1. Palm oil and fractionation

CPO has an equal ratio of saturated and unsaturated fatty acids with 5–9% trisaturated TAG (SSS), 43–49% disaturated TAG (SUS), 38–44% monosaturated TAG (SUU), and 6–8% triunsaturated TAG (UUU) (Azian et al., 2001; Gee, 2007). Table 2 shows the TAG composition of vegetable oils. 1-palmitoyl-2-oleoyl-3-palmitoyl-sn-glycerol (POP) and 1-palmitoyl-2-oleoyl-3-oleoyl-sn-glycerol (POO) are the two main TAGs found in palm oils. POI and PS have the highest POP content. This contrasted with the 0–0.3% POP level of sunflower oil (Farajzadeh et al., 2019), soybean oil (Joki et al., 2010; Li et al., 2017), and canola oil (Endo et al., 2011). At 0.2 and 0.4%, respectively, RPO and CPO have the lowest levels of 1-stearoyl-2-oleoyl-3-stearoyl-sn-glycerol (SOS). Olive (Almoselhy et al., 2019) and sesame (Shi et al., 2017; Toorani et al., 2019) oils are primarily composed of 1-oleoyl-2-oleoyl-3-oleoyl-sn-glycerol, which is thought to be healthier (OOO). CPO is composed primarily of 44–45% palmitic acid, 39–40% oleic acid, and 10–11% linoleic acid (Voon et al., 2019). The *sn-1* and *sn-3* locations are occupied by palmitic and stearic acids, respectively, whereas the *sn-2* position is occupied by oleic and linoleic acids (Marangoni et al., 2017). According to Mancini et al. (2015), high-quality PO is generally utilized as an edible oil in the food

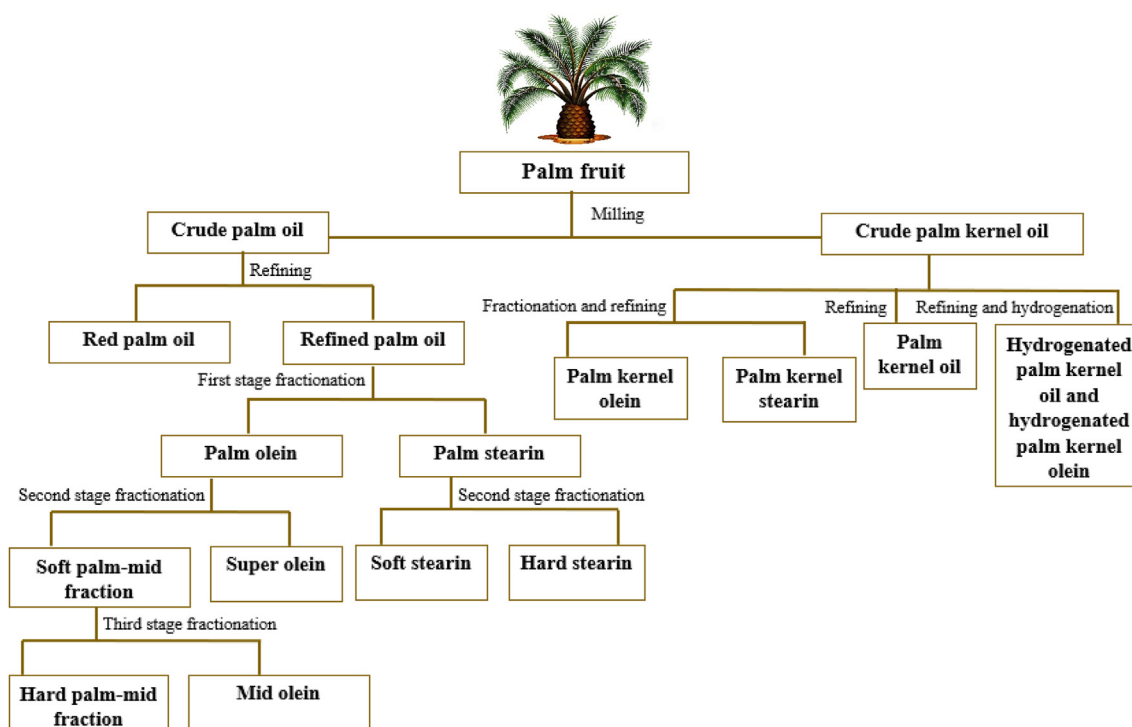


Figure 1. Fractionation of palm oil.

Table 1. Different fractionation methods used in palm oil industry.

Fractionation method	Results	References
Novel layer melt crystallization	<ul style="list-style-type: none"> The melting point and solid fat content of POI increase whereas iodine value decreases. The main TAG in POI is 1,2-Dioleoyl-3-palmitoylglycerol. The melting point and solid fat content of PS decrease whereas iodine value increases. The main TAG in PS is 1,3-dipalmitoyl-2-oleoylglycerol. 	Lu et al. (2021)
Novel isothermal fractionation	<ul style="list-style-type: none"> Diunsaturated TAG were virtually absent in PS obtained. 	Hishamuddin et al. (2020)
Solvent (Acetone)	<ul style="list-style-type: none"> Fractionated PS had high symmetric monounsaturated triacylglycerols content. Hard PMF produced from additional fraction of soft PMF had high 1,3-dipalmitoyl-2-oleoyl-glycerol content. IV of PS changed from 37 to values ranging from 24 to 51. The TAGs composition of PS is concentrated with palmitic acid at sn-2 position. 	Kang et al. (2013) Jin et al. (2018) Podchong et al. (2018) Hasibuan et al. (2021)
Solvent (Polyglycerol esters)	<ul style="list-style-type: none"> The level of POP in POI increases whereas POO decreases. Solvent also enhanced nucleation and retarded crystal growth. PGE influenced the crystal size distribution of PO without affecting the volume of crystals. PGE enhanced the early stages of POI crystallization due to template effects but suppressed the later stages. 	Hao et al. (2019) Saw et al. (2020) Tangsanthakun et al. (2021)
Solvent (Hexane)	<ul style="list-style-type: none"> PS showed lower diacylglycerols content. 	Hwang et al. (2021)
Addition of limonene as green additive	<ul style="list-style-type: none"> Solid fat content, crystallization temperature and cloud point of POI decreases. 	Mello et al. (2021)
Addition of sucrose esters as additive	<ul style="list-style-type: none"> POI crystal size was greatly reduced but the crystal number increased. 	Tangsanthakun and Sonwai (2019)
Dry fractionation	<ul style="list-style-type: none"> Change in ratio between the crystallizing monounsaturated TAGs due to high viscosity of crystal slurry. PMF was obtained at a yield of 24.1% with IV of 45.8 and slip melting point of 42.7 °C. Cloud point, melting point and iodine value of POI increases. Co-crystallization properties are highly modified by tempering depending on the polymorphic properties. 	Calliauw et al. (2007) Nusantoro et al. (2009) Hashem et al. (2018) Gibon and Danthine (2020)
Wet fractionation	<ul style="list-style-type: none"> PS is concentrated with high melting triacylglycerols. 	Kyselka et al. (2018)

Abbreviations: O = Oleic acid; P = Palmitic acid; POI = Palm olein; PS = Palm stearin.

sector since it includes 95% neutral TAGs and less than 0.5% low free fatty acids, as well as low impurity content and good bleaching.

Saw et al. (2020) studied the effect of polyglycerol ester (PGE mix-8) additive on PO fractionation an isothermal temperature of 24 °C in relation to crystal size distribution. Their findings proved that the crystal size distribution was shifted to the smaller region when high amounts of PGE mix-8 additive were used. Fractionation of PO can also be carried out through isothermal fractionation at 24, 26, 28, 30, and 32 °C. The crystallization process was initially dominated by trisaturated TAGs and later by the monounsaturated TAGs once the trisaturates had depleted from the liquid (Hishamuddin et al., 2020). Valasques et al. (2020) introduced a simple and straightforward extraction as an alternative treatment to the digestion sample when the matrices are difficult to attack and decompose. The authors used extraction induced by emulsion breaking at a temperature of 90 °C to allow phase separation of crude PO. A recent study conducted by Gibon and Danthine (2020) and found that unsaturated fatty acids are poorly soluble in fully saturated TAGs, and the formation of molecular compounds by OPP (Oleate-Palmitate-Palmitate) was also observed. However, there is difficulty to control the heat release in the systems containing POP (1-palmitoyl-2-oleoyl-3-palmitoyl-sn-glycerol) and OPP (1-oleoyl-2-palmitoyl-3-palmitoyl-sn-glycerol) during the fractionation process. Modification of crystallizer could be helpful to provide more effective cooling and agitation systems as the crystallizer has a direct impact on mass and heat transfer during PO fractionation.

2.2. Palm olein and fractionation

Fractionating RPO yields the liquid fraction called palm olein (POI). POI is largely composed up of oleic (43%) and palmitic (41%) acids, with a minor amount of linoleic acid (11%) (Koohikamali and Alam, 2019). In terms of fatty acid content, POI differs from the other palm oils (CPO and PS) in that it is largely constituted of oleic acid (C18:1), making it more like other unsaturated vegetable oils such as olive oil (Mateos et al., 2005; Almoselhy et al., 2019) and canola oil (Beyzi et al., 2019) (Table 3). According to Koushki et al. (2015), standard olein (IV of 56–59 and CP of 10 °C) and super olein (IV of >60 and CP of 2–5 °C) are the two types of palms olein. Due to a substantially lower SFC than ordinary

olein, super olein is more transparent and has a lower CP. Super olein is also suited for use as a frying medium in cooking and frying oils because of its high tocotrienol content (Goon et al., 2019).

The temperature range for POI fractionation is narrower, the mass and heat transfer management are more complex, and complicated filtration step is involved (Calliauw et al., 2007; Gibon and Danthine, 2020). Mello et al. (2021) recently employed limonene as an additive to address the technical difficulty of POI being cloudy at low temperatures. They discovered that limonene reduced SFC, crystallization temperature, and cloud point by around 10%, resulting in superior cold stability resistance. POI was also crystallized at 13 °C for 335 min in the presence of polyglycerol esters (PGE) (Hao et al., 2019). The best performance was achieved with a dosage of 0.3% (w/w) PGE, which produced the most medium-sized crystals. Tangsanthakun et al. (2021) discovered that solid state PGE improved the early phases of POI crystallization through template effects but suppressed the latter stages of POI crystallization. Previously, Tangsanthakun and Sonwai (2019) found that addition of sucrose esters during fractionation increased the crystal number of POI with decreasing crystal size. Fractionation of POI is more complex; therefore, filtration procedures should be chosen carefully to reduce liquid oil entrainment in the PS fraction, which resulting in the highest possible yield of POI.

2.3. Palm stearin

The solid component of RPO is palm stearin (PS), which contains 29–35% SSS, 43–49% SUS, 19–21% SUU, and 3–4% UUU (Kanagaratnam et al., 2020). PS is rich in palmitic acid and the oleic acid content is about half of the palmitic acid. PS has a low IV value and a high slip melting point (Goon et al., 2019), making it appropriate for use as a natural hard stock in the production of trans-free fat food products, soap, and oleochemicals (Flores Ruedas et al., 2020).

Podchong et al. (2018) fractionated PS with acetone and found that PS was made up of spherulites with massive rod-like crystals. Solvent fractionation has a high separation efficiency and increases the yield of the targeted phase (Kyselka et al., 2018; Hwang et al., 2021). This serves as foundation for the development of baking margarine and pastry

Table 2. Triacylglycerols composition of fractionated palm oil and other vegetable oils.

Sources	PLO (%)	PLP (%)	OOO (%)	POO (%)	POP (%)	PPP (%)	POS (%)	SOS (%)	SOO (%)	References
CPO	10.5	8.7	4.0	22.1	29.1	5.6	4.9	0.4	2.3	Sehgal and Sharma (2021), Gibon and Danthine (2020)
RPO	6.6	6.4	5.7	22.2	17.9	6.8	3.5	0.2	1.8	Azian et al. (2001), Gee et al. (2007)
POI	9.2	7.4	2.8	33.1	36.4	0.9	4.2	-	2.3	Ly et al. (2018), Mello et al. (2021)
PS	6.2	8.0	2.9	17.8	36.7	12.5	5.9	0.4	1.3	Kanagaratnam et al. (2020), Podchong et al. (2018)
PKO	-	-	1.6	1.5	0.8	0.2	0.2	0.3	-	Choudhary and Grover (2019), Sehgal and Sharma (2021)
Olive oil	5.5	1.3	41.0	15.5	2.3	-	1.0	-	5.2	Mateos et al. (2005), Almoselhy et al. (2019)
Soybean oil	13.7	1.3	2.0	2.2	-	-	0.9	-	-	Jokić et al. (2010), Li et al. (2017)
Sunflower oil	5.7	0.4	38.7	6.4	0.3	0.4	0.2	-	0.6	Farajzadeh et al. (2019)
Sesame oil	12.0	2.1	14.5	8.1	1.3	-	1.1	0.5	2.8	Shi et al. (2017), Toorani et al. (2019)
Canola oil	1.6	1.1	28.7	5.8	-	-	-	-	2.4	Endo et al. (2011), Beyzi et al. (2019)

Abbreviations: PLO = 1-palmitoyl-2-linoleoyl-3-oleoyl-sn-glycerol; PLP = 1-palmitoyl-2-linoleoyl-3-palmitoyl-sn-glycerol; OOO = 1-oleoyl-2-oleoyl-3-oleoyl-sn-glycerol; POO = 1-palmitoyl-2-oleoyl-3-oleoyl-sn-glycerol; POP = 1-palmitoyl-2-oleoyl-3-palmitoyl-sn-glycerol; PPP = 1-palmitoyl-2-palmitoyl-3-palmitoyl-sn-glycerol; POS = 1-palmitoyl-2-oleoyl-3-stearoyl-sn-glycerol; SOS = 1-stearoyl-2-oleoyl-3-stearoyl-sn-glycerol; SOO = 1-stearoyl-2-oleoyl-3-oleoyl-sn-glycerol.

shortening (Podchong et al., 2018). After PS fractionation at 4 °C for 24 h using two-stage acetone fractionation, a solid fraction with a total symmetric monounsaturated triacylglycerols (SMUT) concentration of 63.2 g/100 g was produced (Kang et al., 2013). Due to the high SMUT concentration, this type of fractionation is excellent for preparing cocoa butter equivalent. However, producing fractions with well-defined physical qualities, which may be ideal for specific processed food applications, may be possible.

2.4. Palm mid fraction

Palm mid fraction (PMF) is made by fractionating either palm olein or palm stearin. According to Jin et al. (2018), the fractionation of POI and PS yields three forms of PMF: PMF-A, PMF-B, and PMF-C. PMF-A (IV, 48.4 g/100 g), also known as soft PMF, is typically produced by dry fractionation of POI or rapid chilling of PMF-B. At high temperatures, PMF-A included 43.8% POP with softening qualities (SMP, 27.6 °C; SFC, 30 °C, 2.2%) (Danthine et al., 2017). PMF-B (IV, 42.3 g/100 g) is fractionated from PS or PMF-A using acetone in a 1:4–8 (w:v) ratio at 17–25 °C for 8–48 h. PMF-B has a high level of 1,2,3-tripalmitoyl-glycerol (6.2%), which improves its thermal performance (SMP, 34.9 °C; SFC at 30 °C, 13.8%). γ -tocopherol and campesterol in PMF-A and PMF-B reduce lipid oxidation during frying, making them appropriate for creating margarine shortenings and frying fats (Kumar and Krishna, 2014). Further fractionation of PMF-A or PMF-B in the presence of acetone at a 1:10 (w:v) ratio at 4 °C for 24 h yields PMF-C (IV, 33.0 g/100 g). PMF-C had the largest percentage of POP (67.1%) and shown heat

resistance (SMP, 31.8 °C; SFC at 30 °C, 22.4%). PMF-C's steep SFC profile suggests that it could be used to make hard chocolate fats (Kang et al., 2013). Seeding agents either indigenous or added later can be employed to increase the applications of PMF in the food industry as these agents can modify PMF's physical structure.

3. Applications of palm oil in the food industry

Due to its distinctive solid content profile, which includes exceptional oxidative stability and high nutritional value, approximately 80% of refined and fractionated PO is employed in the food industry (Figure 2). Refined palm oil and palm olein are used as culinary oils whereas palm stearin is utilized as a baking fat because of its stable β' polymorphic form (Dian et al., 2017). Moreover, palm olein is ideal for confectionary fats due to its high lauric acid concentration and acute melting point. RPO is also utilized in the production of cheese to increase physicochemical qualities and to improve sensory metrics (Javidipour and Tunçtürk, 2007). Customers have always been concerned about the SFAs level of PO and its fractionated components, thus blending with other unsaturated vegetable oils and fats, such as olive oil, has been done to provide a healthier option in terms of fatty acid composition.

3.1. Frying medium

RPO and POI are excellent cooking and frying oils with exceptional oxidative stability due to their high amount of oleic acid and natural antioxidants. RPO is a favorite cooking, grilling, and frying oil among

Table 3. Major fatty acid profile of fractionated palm oil and other vegetable oils.

Sources	C12:0 (%)	C14:0 (%)	C16:0 (%)	C18:0 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)	C20:0 (%)	References
CPO	0.3	1.3	43.6	4.2	38.9	10.4	0.3	0.3	Choudhary and Grover (2019), Sehgal and Sharma (2021)
PKO	51.8	17.0	7.9	1.9	12.2	2.0	-	0.2	Choudhary and Grover (2019), Sehgal and Sharma (2021)
POI	0.5	1.2	35.5	4.1	46.2	12.0	0.3	0.5	Ly et al. (2018)
PS	0.4	1.6	60.6	5.1	25.4	6.2	0.3	0.4	Farajzadeh et al. (2019), Podchong et al. (2018)
Olive oil	-	-	13.8	2.8	69.0	12.3	0.8	-	Almoselhy et al. (2019)
Soybean oil	-	-	10.6	3.8	24.4	53.3	8.1	-	Jokić et al. (2010), Li et al. (2017)
Sunflower oil	-	0.3	11.3	4.4	25.9	56.6	0.4	-	Farajzadeh et al. (2019), Wang et al. (2018)
Sesame oil	0.2	0.3	11.3	4.7	35.0	45.0	0.4	0.4	Shi et al. (2017), Toorani et al. (2019)
Canola oil	-	-	5.1	2.0	57.5	22.7	9.2	-	Endo et al. (2011), Beyzi et al. (2019)

Abbreviations: C12:0 = Lauric acid; C14:0 = Myristic acid; C16:0 = Palmitic acid; C18:0 = Stearic acid; C18:1 = Oleic acid; C18:2 = Linoleic acid; C18:3 = Linolenic acid; C20:0 = Arachidic acid.

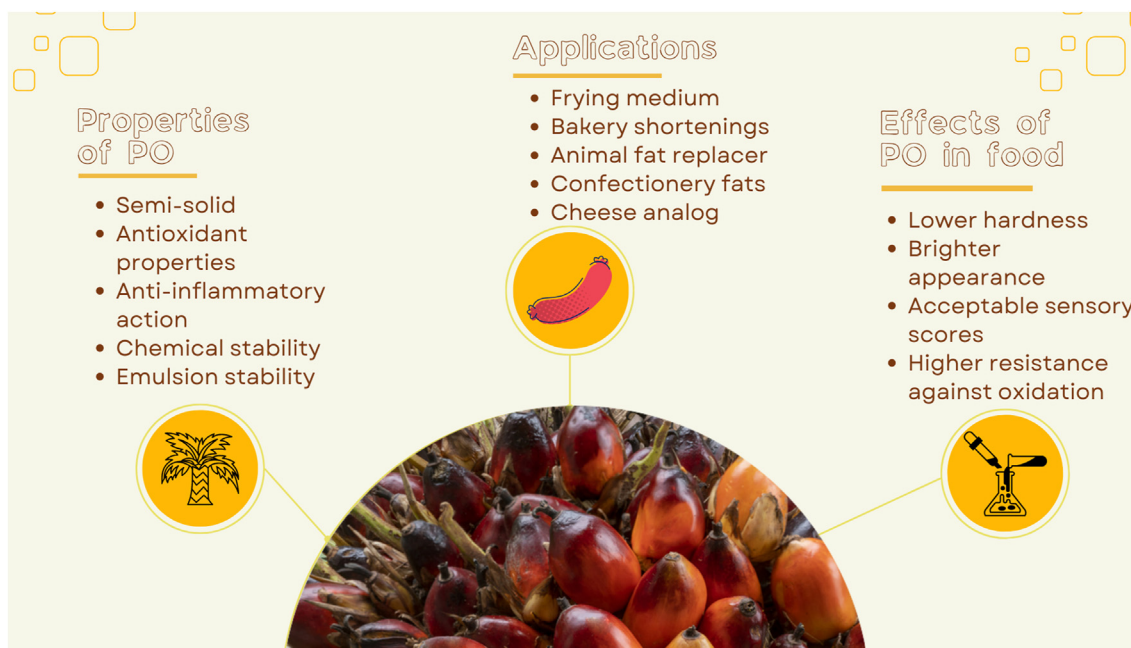


Figure 2. Applications of fractionated PO in the food industry.

customers because it is the most stable oil in industrial frying (Dian et al., 2017). Despite health concerns regarding SFA consumption, RPO is still commonly used due to its balanced SFA and USFA content, which provides good oxidation stability and gumming, a high smoke point, low FFA formulation, low rate of foaming and darkening, and a nutritionally sufficient fatty acid composition.

When the potato was continually fried 40 min a day, seven days a week at 165 °C, Paunović et al. (2020) discovered that the peroxide and acid values increased by 77.8% (2.25–4.00 mmol/kg) and 26.8% (0.56–0.71 mg KOH/g), respectively. This shows that the oil was functioning well and was still in good enough condition to be reused at the conclusion of the experiment. Mba et al. (2017) discovered that carotenoids in CPO had a high activation energy (Ea of 71.5 kJ/mol), however tocopherols (tocopherols and tocotrienols) were less stable when tested under deep-fat frying temperatures between 170–190 °C. Additionally, POI was the most stable against oxidation rancidity when compared to soybean, sunflower, and canola oils (Siddique et al., 2010).

Using RPO as a cooking oil can also be combined with other liquid vegetable oils to create a unique flavor. Blending lowers the linoleic and linolenic acid content of liquid vegetable oils in a similar way to partial hydrogenation without introducing trans isomers of FAs (Siddique et al., 2010). When RPO was combined with refined olive pomace oil at a 25:75 ration, Hammouda et al. (2017) found no endogenous synthesis of 3-MCPD and glycidyl esters after 16 h of deep-frying. Zribi et al. (2016) discovered that the refined olive oil and RPO blend had the maximum chemical stability throughout the frying process of potatoes, whereas the soybean and RPO blend has low stability. It could be worthwhile to investigate the nano encapsulation of antioxidants to suppress the oxidation process to assure the stability of PO or blended PO after frying.

3.2. Bakery shortenings

Shortening is a visco-elastic semi-solid food product. A good bakery shortening has a melting point of >38 °C with solid fat content (SFC) of 15–25% at 20 °C. PO's SFC is between 22 and 25% at 20 °C, resulting in a consistency like plastic cake shortening (Nor Aini and Miskandar, 2007). In bakery goods, however, 100% PO shortening performs poorly since the products do not hold enough air during preparation, resulting in low volume (Dian et al., 2017). Palm kernel oil enhances the crystal stability

in the β' form when added to PO-based shortening (Jin et al., 2008). This showed that combining palm oil with other oils and fats can yield shortenings that are comparable to commercially available partially hydrogenated liquid oils shortenings (Reshma et al., 2008).

After four weeks of storage, the hardness of RPO- and PS-based puff pastry shortening shows no significant change, according to a study on cooling impact by Nguyen et al. (2021). Long-term storage at 5 °C revealed several big aggregates related to palm fat crystal recrystallization. Similarly, PO-based shortening demonstrated that the volume, surface color, and texture of a cake created from PMF-B and POI were comparable to those made from conventional margarine (Goh et al., 2019). Fu et al. (2018) found that palm-based shortenings increased the volume and crumb structure of the cake by assisting air incorporation and retention in the batter. When roughly 10% PO shortening is added during bread baking, data show that it enhances bread volume and oven spring to an optimal level of 4% (Chin et al., 2010). Yanty et al. (2017) also discovered that shortening prepared from a blend of PO, soybean oil, and lipids had similar consistency, hardness, compression, and adhesiveness as lard shortening. Additionally, Rudisari et al. (2019) found that a 90:10 blend of Ardeh oil and PS had the lowest peroxide value (0.164 mEqO₂/kg) and free fatty acids (0.1%). Alternatively, oleogels in PO-based shortening using monounsaturated fatty acids as the base oil can be used to provide a healthier alternative while preserving the desired texture in baked goods.

3.3. Animal fat replacer

Animal fat is used to make processed meats such nuggets, frankfurters, and patties, where it interacts with other ingredients to give the final product a unique texture and flavor profile (Cáceres et al., 2008). Denatured proteins produce a semirigid membrane with unique visco-elastic characteristics that prevent liquified fat from expanding during heating (Barbut, 2015). However, due to SFAs, trans fatty acids, and cholesterol, it is thought that eating animal products contributes to a variety of disorders such as obesity and hypertension (Ospina-E et al., 2012). As a result, there is a critical need to develop a healthy alternative to meet the growing demand for healthy eating and living among consumers. Vegetable oil, rather than animal fat, is one of the options since it can eliminate or at least lessen the risk to human health (Asamoah, 2019).

According to Mbougeng et al. (2017), there was no significant change in the physicochemical parameters of liver patties prepared with 20% bleached PO and 30% pork fat. Panpipat and Chaijan (2017) discovered that tilapia sausages made of PS had significantly increased lightness ($L^* = 18.6$), redness ($a^* = 8.4$), and yellowness ($b^* = 16.9$) values, indicating that the color of the sausage had significantly improved. Lower instrumental hardness (8.1 kg), springiness (0.8 cm), and chewiness (0.3 J) were also observed along with the less expressible fluid (18.8%). Furthermore, Wang et al. (2018) discovered that employing RPO at 50% as a fat substitute in emulsified sausage resulted in lower fat content (17.01%), reduced cooking loss (4.72%), higher moisture content (56.95%), and higher lightness values (74.02) than the control sample. Asamoah (2019) revealed that sausages made with rabbit meat and PS had good sensory criteria (3.44), a greater protein level (23.73%), and lower fat levels (8.77%) than sausages made with beef or lard. PO may be integrated into a hydrogelled emulsion to effectively duplicate the functions of animal fat with the added benefit of a healthier lipid profile.

3.4. Confectionery fats

Chocolate, whipped cream, and confectioneries all employ cocoa butter as a traditional basic ingredient (Norazlina et al., 2021). Cocoa butter has a great mouthfeel taste and desirable processing qualities due to its unique physicochemical properties. However, because of the diminishing global supply of cocoa driven by climate and environmental change, using cocoa butter is quite expensive (Biswas et al., 2016). Hence, palm fats are recommended as a cocoa butter substitute due to their physicochemical qualities (Jahurul et al., 2014; Hassim and Dian, 2017).

According to Said et al. (2019), POI chocolate spread is easier to spread since its firmness reflects its spread ability. Among the maize oil (1000 g) and olive oil (1200 g) spreads, POI exhibited the lowest firmness (600 g). In the manufacture of chocolate, Zhang et al. (2020) employed interesterified fats consisting of POI, fully hydrogenated PO, and palm kernel oil. The results demonstrated that the chocolate possessed the requisite hardness and fracturability parameters without the requirement for tempering. Besides, Biswas et al. (2017) looked at the physical qualities of chocolate made with PS and PMF as cocoa butter substitutes. The authors found no evidence of bloom formation in chocolate made with 20 g PO-based substitute and stored at 24 °C and 29 °C for 12 weeks.

PO can be blended with other vegetable oils to make confectionery fats since the combination can give the characteristics needed. Sonwai et al. (2014) demonstrate this by preparing confectionery fats by blending mango kernel fat with PMF at different proportions. The mixtures were high in palmitic (10.3–29.1%), oleic (38.7–40.0%), and stearic (24.7–42.8%), according to the fatty acid composition. Ma et al. (2019) showed that combining *Cinnamomum camphora* seed oil with fully hydrogenated PO increased the spread ability of confectionery items. The inclusion of PO can be done using lipid microparticles, which leads to the production of small nuclei, to produce excellent stability and thermal resistance in confectionery products.

3.5. Cheese analog

Cheese replacements or imitations are chosen over natural cheese because they are less expensive to produce and give nutritional benefits (Dian et al., 2017). To replace milk fat, vegetable oils are commonly employed to make cheese alternatives. It has been proven that substituting monounsaturated and polyunsaturated fatty acids for milk fat decreases blood cholesterol levels in adults (Aljewicz et al., 2011). Because of its natural tocopherol content, PO is suitable to substitute milk fat in the production of cheese analogues (Noronha et al., 2007).

Abdel-Ghany et al. (2020) investigated the chemical composition, antioxidant activity, and oxidative stability of full fat, half fat, and low-fat cheese analogues using PO as a milk fat substitute. After three months of

storage, the processed cheese analogues showed little changes in dienes and thiobarbituric acid (TBARS) readings, indicating stability against oxidation. Yagoub et al. (2016) discovered that Mozzarella cheese with 2% PO had better organoleptic qualities (4.60) than those with 0% (3.80), 1% (4.30), and 3% (4.10). In a study published by Ismail (2012) looked at the effects of using hydrogenated palm kernel oil (HPKO), palm kernel olein (PKO), and double fractionated palm olein (DFPO) in the production of cheese. PKO and DFPO slightly lowered the pH of processed cheese but had no effect on moisture, fat, or salt levels. Furthermore, the sensory assessment scores of PKO cheese were higher than those of DFPO cheese, at 88 and 81, respectively. This suggests that a diverse variety of flavor versatility cheeses can be manufactured to meet the needs of local consumers.

4. Palm oil and health

Palm oil is high in essential fatty acids, which are necessary for good health. PO and its derivatives are high in vitamin E (560–1000 ppm), with tocotrienol accounting for over 20% of the total. PO has the largest amount of γ -tocotrienol, which has the strongest antioxidant potential, when compared to other vegetable oils (Ganesan et al., 2018). There are previous studies investigated the effects of PO on human health (Voon et al., 2019; Dong et al., 2017), but this article will focus on the role of PO in pathologies by looking at cardioprotective, antidiabetic, anti-inflammatory, and antithrombotic effects in both human (Table 4) and animal (Table 5) studies.

4.1. Cardioprotective effect

In 2015, an estimated 422.7 million cases of cardiovascular disease (CVD) were diagnosed, with 17.92 million deaths due to CVD (Fontecha et al., 2019). CVD is a term used to describe a set of heart and blood vessel illnesses, including coronary heart disease caused by occlusion of coronary vessels by atherosclerotic plaques (Grech, 2003). Meanwhile, ischemic strokes occur due to the occlusion of vascular supply by atherosclerotic plaques, while haemorrhagic strokes are caused by a blood vessel rupture (Deb et al., 2010). The saturated fat in PO, particularly palmitic acid, accelerates the deterioration of cardiovascular health, according to scientists (Kelly and Fuster, 2010). SFA is a precursor of CVD because it boosts low-density lipoprotein (LDL) cholesterol while lowering high-density lipoprotein (HDL) (Karunathilake and Ganegoda, 2018). As a result, some people are concerned that employing PO in foods like confectionery fats and cheese could increase the risk of atherosclerosis.

However, there is no solid evidence linking PO use to the risk of CVD. According to Sun et al. (2015), PO increased LDL cholesterol by 0.24 mmol/L as compared to low-saturated-fat vegetable oils, though the difference is clinically insignificant. Furthermore, Aung et al. (2018) investigated the effects of PO consumption on cholesterol levels in both men and women. The authors found that when PO used for cooking, it only increased blood pressure and total cholesterol in women compared to peanut oil (Aung et al., 2018). Meanwhile, PO reduced the cholesterol level in healthy youth (Alexandre et al., 2017). Previously, Kabagambe et al. (2003) highlighted a connection between individual SFA intake and myocardial infarction risk, where each fatty acid in the blood plasma has a particular effect. In addition, Ospine-E et al. (2012) found that SFAs with 12–16 carbons, such as lauric (C12:0), myristic (C14:0), and palmitic (C16:0), have the most impact on LDL and total cholesterol levels, whereas stearic acid (C18:0) has no effect. Ismail et al. (2018) mentioned that PO is not the only source of SFAs as dairy products and red meat are also substantial sources of SFAs. Additionally, Ismail stated that other factors including medical history and comorbidities, physical activity, and alcohol intake, can also cause CVD. Thus, PO is not the only one to blame (Ismail et al., 2018).

Despite the concerns against PO, it has been demonstrated that the presence of oleic acid in PO is cardioprotective. At comparison to

Table 4. Significant human studies on beneficial health effects of PO.

Reference	Country	Design	Subjects	Duration	Test oils	Intervention	Key findings
Lv et al. (2018)	China	Randomized, parallel, single-blind	88 M & F aged 20–40 y	16 w	POI	20–22 g per day	No significant different in LDL-C and HDL-C
Ng et al. (2018)	Malaysia	Randomized, double – blind, parallel	23 M & 67 F, aged 20–60	8 w	POI	2 cupcakes and 5 pieces of cookies (33% w/w POI per day)	↓ weight gain, ↓ changes in body fat and leptin concentration
Alexandre et al. (2017)	Côte d'Ivoire	Randomized, cross-sectional	120 M & F aged 18–30 y	6 w	PO	25 g	↓ cholesterol, no changes in lipid and lipoprotein profile
Hyde et al. (2021)	United States	Randomized, controlled feeding, cross-over	24 M & F, aged 21–65 y	13 w	PS	40% fat from 2500 kCal per day	PS reduced oxidized LDL compared to butter
Cheng et al. (2019)	China	Randomized, cross-over	72 M & F aged 20–40 y	16 w	POI, olive oil	30% fat from 2000 kCal per day	↓ serum triglyceride than extra virgin olive oil
Sun et al. (2018)	China	Randomized, double-blind crossover	120 M & F	10 w	POI, olive oil	48 g	No significant different in BMI and HDL-C between POI and olive oil
Teng et al. (2011)	Malaysia	Randomized, single-blind	10 M aged 21 y	12 d	POI	50 g	No significant different in plasma glucose, insulin, and adipocytokines
Sundram et al. (2007)	Malaysia	Randomized, crossover	19 M & F	4 w	POI	53 g	↓ LDL/HDL ratio and fasting blood glucose
Takeuti et al. (2014)	Brazil	Randomized, controlled	5 M & 6 F aged 21–60 y	2 d	PO	9 g	↓ glycemia
Mo et al. (2019)	Malaysia	Randomized, double-blind crossover	6 M & 15 F aged 30–60 y	13 m	POL, interesterified POL	Muffin made of 50 g POI and interesterified POI	↓ plasma GIP concentration
Voon et al. (2015)	Malaysia	Randomized, crossover	9 M & 36 F aged 20–60 y	3 w	POI, olive oil, coconut oil	30% kCal fat/day	No significant change in thromboxane and cell adhesion
Reddy and Sesikaran (1995)	India	Cross-over	12 M & 12 F aged 29–39 y	16 w	POI	32% from total fat per day	No significant change in plasma aggregation

Abbreviations: PO = Palm oil; POI = Palm olein; PS = Palm stearin; GIP = Glucose-dependent insulinotropic polypeptide.

polyunsaturated and monounsaturated fatty acids, saturation in the *sn*-2 position has a larger cholesterol-increasing effect, according to Yilmaz and Agagunduz (2020). The induced blood lipid levels are determined by the saturation or unsaturation of fatty acids located at the *sn*-2 locations of TAG in fat molecules, not the overall saturation of oils. Even though PO is 50% saturated, it does not behave like a saturated fat (Teh et al., 2018). *sn*-2 position of TAGs in PO was predominantly esterified with oleic acid with only 10–15% of total palmitic acid and 6–20% of stearic acid acylated in the secondary position. Longer chain SFAs located at the *sn*-1, 3 position of the TAG backbones reduced changes in body fat percentage and leptin concentration in 90 individuals who consumed cupcakes and cookies containing 33 percent w/w POI daily (Ng et al., 2018).

A previous study by Lv et al. (2018) demonstrated that HDL-C and LDL-C of 88 POI-supplemented subjects did not change significantly during the 16-week intervention. This result agrees with Cheng et al. (2019), who found that the blood triglyceride level in POI-diet was much lower than extra virgin olive oil, possibly due to individual fatty acid absorption and metabolism. Sun et al. (2018), on the other hand, showed no significant differences between POI and olive oil consumption in serum total cholesterol, LDL-C, or HDL-C. In addition, due to increased

quantities of myristic and lauric acid in butter, butter was observed to enhance LDL-C in 24 participants when compared to a PS-based diet (Hyde et al., 2021).

4.2. Antidiabetic effect

Diabetes was diagnosed in 415 million adults (8.8%) in 2015, and this number is anticipated to climb to 642 million (10.4%) by 2040 (Atlas, 2015). Resistance to insulin and increasing beta cell failure characterize the condition, and hyperglycemia is a key factor in the development of diabetes complications (Budini et al., 2009). Diabetic nephropathy is a severe consequence of diabetes and the primary cause of end-stage renal failure worldwide. Furthermore, diabetic nephropathy patients have a higher risk of cardiovascular events, hospitalizations, cognitive dysfunction, and poor quality of life (Etgen et al., 2012). While some researchers believe that saturated fat consumption causes type 2 diabetes, the link between PO consumption and diabetes risk is yet unknown (Liu et al., 2019). Hasrini et al. (2017) tested the antidiabetic and immunomodulatory potential of purple soymilk enriched with CPO on diabetic patients. According to these authors, the product reduced fasting

Table 5. Animal and *ex vivo* studies on anti-inflammatory and antithrombotic of PO.

Diets	Intervention	Subjects	Key findings	References
TRF	1.0 µg/mL	Human monocytic cells	↓ the release of proinflammatory cytokines, NO and PGE ₂	Wu et al. (2008)
TRF, RBD-stripped vitamin E oil	30 mg/kg	30 female Dark Agouti rats	↓ articular index scores and cytokines level	Zainal et al. (2019)
RPO, olive oil	55% energy from RPO	40 male Wistar rats	Both RPO and olive oil diets ↑ myokines gene expression	Gauze-Gnagne et al. (2020)
POI, olive oil	55% energy from POI	24 male Wistar rats	No significant changes in interleukin-6 and oxidative stress parameters	Djohan et al. (2021)
RPO	-	6 male Wistar rats	↓ fibrinogen, ↑ antithrombin levels	Pereira et al. (1991)

Abbreviations: PO = Palm oil; POI = Palm olein; PS = Palm stearin; RPO = Refined palm oil; RBD = Refined bleached deodorized; TRF = Tocotrienol rich fraction; NO = Nitric oxide; PGE₂ = Prostaglandin E₂.

blood glucose (Control, 177.20 mg/dL; Test group, 154.87 mg/dL) and haemoglobin-A1c level (Control, 0.29 OD450; Test group, 0.26 OD450) while increasing the insulin level (Control, 0.18 OD450; Test group, 0.21 OD450), thus, indicating antidiabetic activities.

SFAs increase insulin resistance in muscle cells in vitro, whereas unsaturated fatty acids improve insulin sensitivity (Lee et al., 2006). This conclusion, however, is not consistent. Teng et al. (2011) studied the effects of POI and olive oil supplementation on 10 healthy male students and found that the type of dietary fat had no effect on plasma glucose and insulin levels. Because POI does not interfere with insulin secretion, Sundram et al. (2007) observed a 20% drop in fasting blood glucose compared to interesterified fat. Subsequently, POI lowered glucose-dependent insulinotropic polypeptide, due to improved digestibility and enhanced affinity of lipoprotein lipase for TAGs with palmitic acid in the *sn-2* position rather than the *sn-1* position (Mo et al., 2019).

Furthermore, the antidiabetic effect of refined PO is mediated by two mechanisms: tocopherol action and increased incretin levels. Although total tocopherol content decreased after refining and fractionation steps, the residual tocopherol (RPO, 563 ppm; POI, 643 ppm; PS, 261 ppm) is sufficient to lower malondialdehyde levels, as demonstrated by (Wong et al., 1988). Malondialdehyde levels beyond a certain threshold indicate poor metabolic control (de Souza Bastos et al., 2016). Takeuti et al. (2014), on the other hand, discovered that PO raised circulating incretin levels, which is a hormone generated by the intestine to induce insulin secretion. PO's mechanism for lowering diabetes risk differs from that of other vegetable oils like canola oil. Salar et al. (2016) found that canola oil consumption significantly lowered total cholesterol and LDL-C levels in 75 postmenopausal women with type 2 diabetes. Coconut oil, on the other hand, has an antidiabetic effect by balancing blood sugar levels (Deen et al., 2021). Thus, PO and other edible oils may be used as a good base for antidiabetic drug formulations to boost bioavailability and rapid release.

4.3. Anti-inflammatory activity

Inflammation is a long-evolved process that involves the body's reaction to tissue damage caused by physical injury, ischemic injury, infection, toxins, or other types of trauma (Greten and Grivnickov, 2019). The inflammatory response of the body generates cellular alterations and immunological responses, which result in tissue repair and cellular proliferation. However, inflammation may become chronic if the cause of the inflammation persists or control mechanisms fail to function, resulting in cell mutation (Singh et al., 2019). Chronic inflammatory disorders have been identified as the leading cause of death in the world today, accounting for more than half of all deaths. Inflammation-related diseases include cancer, chronic kidney disease, Alzheimer's disease, autoimmune diseases, and neurological diseases (Furman et al., 2019).

Despite the dearth of study on the possible influence of PO on cancer occurrence, some research findings suggest that PO may be a risk factor due to the creation of acrylamide through glycerol breakdown when PO is heated above the smoke point, particularly when used as cooking oil (Mughtaridi et al., 2012). In contrast to Mughtaridi's finding, Di Genova et al. (2018) reported that there is no relevant impact of PO consumption on cancer risk. Boateng et al. (2006) showed that CPO supplementation aid in colon cancer management by reducing the number of aberrant crypt foci and minimizing the adverse effects of chemotherapy. The same result was observed in dietary canola oil, which is chemo preventive for colon cancer by increasing ω -3 fatty acid levels (Bhatia et al., 2011).

PO's anti-inflammatory properties are also attributed to the action of vitamin E. Vitamin E in PO is distributed as 30% tocopherol and 70% tocotrienols, with 50–65% of the total vitamin E content retained after refining (Sen et al., 2010). In human monocytic cells, Wu et al. (2008) discovered that the tocotrienol-rich fraction (TRF) of PO prevents inflammation by inhibiting the production of inflammatory mediators such as nitric oxide synthase and cyclooxygenase-2. TRF also stopped the

release of nitric oxide and prostaglandin from the cells' lipopolysaccharide. Additionally, TRF demonstrated the ability to diminish inflammation in arthritic rats as compared to refined bleached deodorized (RBD)-stripped vitamin E (Zainal et al., 2019). Vascularity, congestion, pannus growth, articular cartilage damage, subchondral bone damage, and joint space were all reduced as a result of the anti-inflammatory activity.

In comparison to CPO, Gauze-Gnagne et al. (2020) discovered that both RPO and olive oil boosted myonectin expression levels. Myonectin is one of the key myokines to down-regulate inflammatory responses. Because CPO has a higher vitamin E level than RPO and olive oil, the result cannot be attributable to vitamin E. As a result, it is worth noting that the fatty acid distribution in oils may have anti-inflammatory effect. Olive oil, RPO, and CPO have oleic acid values of 66.4%, 39.2%, and 37.4% (Kumar and Krishna, 2014; Mancini et al., 2015; Orsavova et al., 2015). Furthermore, Djohan et al. (2021) found that POI has anti-inflammatory properties comparable to olive oil, with no significant changes in interleukin-6 gene expression between the two. The anti-inflammatory effect of PO is mostly attributed to vitamin E activity and fatty acids distribution; therefore, it is necessary to optimize the processing conditions during extraction and fractionation steps.

4.4. Antithrombotic property

In reaction to tissue injury, thrombosis is induced by a complicated series of biochemical events involving the creation of a fibrin mesh comprising coagulated platelets and other blood cells, known as a thrombus or clot (Kim et al., 2022). However, thrombosis is also the most significant cause of death worldwide, accounting for one out of every four deaths due to the tendency of thrombi to form progressively under pathological conditions, making it one of the significant causes of heart attack and stroke (Wendelboe and Raskob, 2016). Arterial and venous thrombosis are the two types of thrombosis, and both are more common in the elderly (Mackman et al., 2020).

SFAs become a concern since they are thought to increase platelet reactivity, leading to thrombosis (Ashwell, 2012). Boulet et al. (2020) backed this claim by observing increased platelet aggregation in diabetic individuals who consumed RPO-rich hazelnut spread. In contrast to these findings, Pereira et al. (1991) found that RPO lowered fibrinogen levels while increasing antithrombin (ATIII) levels to prevent atheroma formation and lengthen clotting time. POI also has a stronger antithrombotic property than olive oil, according to Voon et al. (2015). POI inhibited the production of thromboxane B2 (TXB2), a substance that causes irreversible platelet aggregation. POI also decreased platelet aggregation by inducing vascular endothelial cells to secrete antithrombotic prostacyclin and prostaglandin F1.

Furthermore, platelet arachidonic acid levels, which are essential drivers of platelet reactivity in vitro, were identical in POI and groundnut oil (Reddy and Sesikaran, 1995). The increased oleic acid content in unsaturated vegetable oils, which is more platelet aggregating than palmitic acid, could explain these findings (Tholstrup et al., 2003). However, more in vitro studies should be undertaken because little is known about the mechanism of PO as an antithrombotic agent. PO is rich in micronutrients such as vitamin E, which may also contribute to antithrombotic activity.

5. Conclusion

PO is rich in saturated fatty acids and has a higher stability than other processed oils, which could extend its shelf life. PO is frequently used because it can be fractionated into POI and PS using fractional crystallization, and the fractionated products have distinct fatty acid and TAG profiles. Hence, this study focuses on the impacts of various fractionation conditions on RPO, POI, and PS, as well as their applicability in the food business. Despite having roughly equal amounts of saturated and unsaturated fatty acids, apparently the unsaturation of PO at the *sn-2*

position does not raise cholesterol levels, resulting in cardioprotective benefits. At the same time, biochemical compounds like tocopherol and tocotrienol could potentially prevent diseases like cancer and diabetes by providing antidiabetic, anti-inflammatory, and antithrombotic capabilities. However, further in vitro research is needed to determine the influence of PO use on consumer health.

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