A Comparison of Palm Oil, Beef Tallow, and Corn Oil Effect on Serum Glucose and Lipid Profile in Rats Fed a High-Fat Diet

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ABSTRACT

This research aimed to investigate the influence of three types of palm oil products (RBDPO (refined bleached deodorized palm oi), RPO (red palm oil), and PKO (palm kernel oil)), on serum glucose and lipid profile of Sprague Dawley rats fed with experimental diet containing 20% of oils, comparing these effects with those of with animal-base oil (beef tallow) including corn oil as a representative from vegetable oil. The diet with level of fat 20% given to two groups (with and without AOM (azoxymethane)) of male Sprague Dawley rats for 13 weeks. The results exhibit that corn oil caused the lowest value of serum glucose ($p < 0.05$) in both AOM and non-AOM groups. Compared to other groups, beef tallow diet significantly increased serum triglycerides, cholesterol, and LDL, followed by RPO/PKO, RBDPO, and corn oil, respectively ($p < 0.05$). Meanwhile, corn oil diet produced the highest level of serum HDL, followed by RBDPO, PKO/RPO, and beef tallow ($p < 0.05$).

Keywords: Beef tallow; corn oil, palm oil; rat; serum

INTRODUCTION

The effect of dietary fat from sources such as beef tallow or vegetable oils on the human body is receiving increased attention due to health concerns. The relationship between dietary fat and several health problems have previously been reviewed including obesity, coronary heart diseases, and increased mortality rates (Al-Hayder et al., 2020). The quality and quantity of fat in a diet has been attributed to the progress of insulin resistance and abnormal levels of lipids in the serum (Akande et al., 2020). Additionally, different fat saturation levels (saturated, mono-unsaturated, and poly-unsaturated) could have different effects on insulin metabolism and glycemic response. Vegetable oils are generally characterized by high content of polyunsaturated fatty acids (PUFA) while relatively low in saturated fatty acids. Previously, it was reported that PUFA could have a significant influence in preventing coronary heart diseases and changes in liver metabolism (Al-Hayder et al., 2020).

There is an increase in vegetable oil use in regular meal preparation and the manufacture of health supplements (Syarifah-Noratiqah et al., 2020). Among these, palm oil (PO) is commonly used in the food processing sector and its use continues to increase to considered as the world's most significant vegetable oil (Kadandale et al., 2019). Generally, based on the part of palm fruit, different types of oil can be produce, for example the mesocarp will produce palm oil, and from the kernel or seed could produce palm kernel oil (PKO) (Edem, 2002). The composition of fatty acid from PO differs significantly from most vegetable oils, where PO could contain palmitic acid up until 44%, while oleic

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acid could reach 39%, make an equal amount of total saturated and unsaturated fatty acids (49%) (Mancini et al., 2015). PKO has a high lauric acid (48%), and myristic acid (16%) content, with a sharp melting profile, making it ideal for confectioneries, edible fats, baked products, soaps, and detergents (Dian et al., 2017; Edem, 2002; Mancini et al., 2015). Palm oil can be used in different forms, including red PO, refined PO, or refined, bleached, and deodorized (RBD) PO. However, the refining process removes the majority of the antioxidants, carotenoids, tocopherols, and tocotrienols during RBD process (Nagendran et al., 2000). Corn oil is another vegetable oil that has been studied for the effect in vivo. A previous study showed that linoleic acid, the main fatty acid in corn oil, has potential health benefits (Pavlisova et al., 2016). Several studies emphasized the advantages of vegetable oils over animal tallow, with excessive intake of beef tallow causing hyperlipidemia (Al-Hayder et al., 2020).

Hyperlipidemia is a metabolism disorder characterized by abnormally high levels of cholesterol or triglyceride in blood and considered as a crucial factor in the development of cardiovascular disease (CVD) (Nie & Luo, 2021). Specific lipid-linked particles play a significant role as CVD-related biomarkers, among them are triglyceride (TG) as the most common type of lipids in the body, cholesterol also known as a waxy substance in the plasma, high-density lipoprotein cholesterol (HDL-C) known as good cholesterol, and low-density lipoprotein cholesterol (LDL-C) known as the bad cholesterol (Syarifah-Noratiqah et al., 2020). Recent studies have suggested a link between the level of lipid in plasma with the risk of colorectal cancer (CRC) (Brantley et al., 2020; Fang et al., 2021). Multiple studies also found that lower levels of HDL, higher levels of LDL, and greater levels of TG were related to an increased risk of CRC (Tian et al., 2015; Yao & Tian, 2015; Zhang et al., 2014). However, the precise significance of dyslipidemia in CRC is uncertain, as some studies have shown contradictory relationship between serum lipids and CRC risk (Brantley et al., 2020; Fang et al., 2021).

In animal and human studies, the observed health benefits of vegetable oils such as palm oil, include cardioprotective agent against ischemic heart disease, preventing atherogenic, hemostat, preventing high blood pressure, and anticancer properties (Loganathan et al., 2017). However, significant disagreements exist regarding the influence on the development of CVD, particularly various serum lipid parameters (cholesterol, TG, HDL/LDL, glucose) (Syarifah-Noratiqah et al., 2020; Szulczewska-Remi et al., 2019). Azoxymethane (AOM) is a derivative of dimethylhydrazine and falls in the category of a direct inducer drug that is considered a good colorectal carcinogen (Jucáa et al., 2014). This study aimed to evaluate how beef tallow, corn oil, RPO, RBDPO, and PKO-containing diets affected serum glucose (Glu), TG, total cholesterol, HDL-C, and LDL-C contents in male Sprague-Dawley rats fed with and without AOM.

METHODS

Materials

The vegetable oils such as RPO, RBDPO, and PKO were obtained from The Indonesian Oil Palm Research Institute, Medan, Indonesia. Corn oil and beef tallow were obtained from the market in Yogyakarta, Indonesia and all chemical reagents were chemical grade. The kit from DiaSys Diagnostic System was used for the determination of Serum Glucose, TG, TC, HDL, and LDL cholesterol levels (DiaSys Diagnostic Systems GmbH, Germany).

Methods

Animal and Diet

Male Sprague Dawley rats (age in average was 3 weeks old) were obtain from the Center for Food and Nutrition Studies Laboratory Animal Center, Gadjah Mada University, placed into individual cages in a room with following conditions, 25-27°C for the temperature, the relative humidity measured for 50-60%, and the light was on for 12 hours and off for another 12 hours. After one week acclimating period (the rats were given pellet meal), the rats divided randomly into five groups (n = 6). The maintenance of the experimental animals was conducted by referring the "Guide for the Care and Use of Laboratory Animals" published by Gadjah Mada University and authorized by the Medical and Health Research Ethics Committee. The five groups of rats were beef tallow, corn oil, RBDPO, RPO, and PKO, were given the experimental diet (*ad libitum*) with the composition as shown in Table 1. The administration of AOM (Sigma, St. Loius, MO) using oral gavage prepared in saline at level of 15 mg/kg body was carried out twice, first in the 2^{nd} week, and the last one in the 3^{rd} week. Thirteen weeks after the experimental diet were given, the animals were sacrificed. To obtain the serum samples, the collected blood were centrifuged at 2000 x *g* using a refrigerated centrifuge for 20 minutes. The serum sampless then stored at –70°C until further analysis.

Determination of Serum Glucose

Serum glucose levels were measured using the Diasys Glucose GOD FS quantification kit, following the manufacturer's instructions (DiaSys Diagnostic Systems GmbH, Holzheim, Germany). Glucose measurements

Table 1. The compositions of expperimental diets (% by weight)

Ingredient	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Casein	20.00	20.00	20.00	20.00	20.00
Corn starch	39.95	39.95	39.95	39.95	39.95
Vitamin (AIN-93)	1.00	1.00	1.00	1.00	1.00
Minerals (AIN -93)	3.50	3.50	3.50	3.50	3.50
Cellulose	5.00	5.00	5.00	5.00	5.00
Sucrose	10.0	10.0	10.0	10.0	10.0
L-Cystine	0.30	0.30	0.30	0.30	0.30
Choline	0.25	0.25	0.25	0.25	0.25
Beef tallow	20.00	-	-	-	-
Corn Oil	-	20.00	-	-	-
RBDPO	-	-	20.00	-	-
RPO	-	-	-	20.00	-
PKO	-	-	-	-	20.00

RBDPO- refined bleached deodorized palm oil; RPO- red palm oil; PKO- palm kernel oil

were obtained after enzymatic oxidation by glucose oxidase. Based on Trinder's reaction, the colorimetric indicator used was quinoneimine, generated from 4-aminoantipyrine and phenol by hydrogen peroxide under the catalytic action of peroxidase (Barham and Trinder, 1972). In this method, 10 μL serum was mixed with a 1000 μL reagent kit, incubated for 10 minutes at room temperature, and the absorbance was read against the blank with a wavelength of 500 nm in 60 minutes.

Determination of Serum Triglyceride

Serum triglyceride level was determined using the DiaSys Triglycerides FS quantitation kit (DiaSys Diagnostic Systems GmbH, Holzheim, Germany). This method was based on the colorimetric enzymatic test using glycerol-3-phosphate-oxidase (GPO). Triglyceride determination occurred after enzymatic splitting with lipoprotein lipase. The indicator used was quinoneimine which was produced from 4-aminoantipyrine and 4-chlorophenol in the presence of hydrogen peroxide, catalyzed by peroxidase. The procedure involved mixing 10 μL serum with a 1000 μL reagent kit, incubating for 10 minutes at room temperature, and reading the absorbance against the blank, with a wavelength of 500 nm in 60 minutes.

Determination of Serum Total Cholesterol

Serum total cholesterol level was determined using the DiaSys Cholesterol FS quantitation kit (DiaSys Diagnostic Systems GmbH, Holzheim, Germany). This method was based on an enzymatic photometric test, with cholesterol determination by enzymatic hydrolysis and oxidation (Barham and Trinder, 1972; Deeg and Ziegenhorn, 1983). Based on Trinder's reaction, the colorimetric indicator used was quinoneimine, produced from 4-aminoantipyrine and phenol in the presence of hydrogen peroxide, with peroxidase serving as the catalyst (Barham and Trinder, 1972). In this method, 10 μL serum was mixed with a 1000 μL reagent kit, incubated for 10 minutes at room temperature, and the absorbance was read against the blank with a wavelength of 500 nm in 60 minutes.

Determination of HDL-Cholesterol

Serum HDL-cholesterol level was determined using the DiaSys HDL-c direct FS quantitation kit (DiaSys Diagnostic System GmbH, Holzheim, Germany). This method was based on the direct determination of HDL cholesterol using a homogenous method without the need for centrifugation (Langlois and Blaton, 2006). Block polymer detergents protected LDL, VLDL, and chylomicrons, enabling the selective determination of HDL-cholesterol through an enzymatic cholesterol measurement (Miida et al., 2014). The level of cholesterol concentration can be obtained by measuring the intensity of the formed dye photometrically. This was conducted by mixing 1 μL serum with 80 μL reagent 1 and 20 μL reagent 2 and measuring the absorbance against the calibrator at a wavelength of 596 nm.

Determination of LDL-Cholesterol

Serum LDL-cholesterol level was determined using the DiaSys LDL-c direct FS quantitation kit (DiaSys Diagnostic System GmbH, Germany) by mixing 1 mL serum with 80 mL reagent 1 and 20 mL reagent 2 before measuring the absorbance against the calibrator at a wavelength of 596 nm. This method was a homogeneous method without centrifugation for direct measurement of LDL-cholesterol. Block polymer detergents protected HDL, VLDL, and chylomicrons, ensuring selective determination of LDL-cholesterol by an enzymatic cholesterol measurement (Nauck et al., 2002).

Statistical Analysis

Values were denoted as the mean and standard error of the mean (SEM). One-way ANOVA was performed to compare mean values. When a significant effect was resulted with the one-way ANOVA, a Tukey-Kramer post hoc test was performed. The software SPSS Statistics for Mac version 26.0 (IBM SPSS Statistics, Chicago, USA) was used to analyze the data. The data considered as significangt different if the value of $p < 0.05$ was occured.

RESULTS AND DISCUSSION

The final body weight of rats were higher in beef tallow group than in corn oil and palm oil groups ($p < 0.05$), in both AOM and non-AOM groups (Table 2). No differences in body weight between corn oil and palm oil groups ($p > 0.05$) were observed, particularly in non-AOM group. Previous studies reported no significant differences in final body weight between added palm oil (2000 mg/kg diet) and a control western diet (red meat 250 g/kg and sunflower oil 70 g/kg diet) (Conlon et al., 2020). The results suggested that palm oil and corn oil did not induce weight increase as observed with animal fat (beef tallow).

Serum glucose levels were higher in beef tallow group than in corn oil and palm oil-fed rats ($p < 0.05$) in both AOM and non-AOM groups (Table 3). There were no differences in serum glucose levels between corn oil and RBDPO groups ($p > 0.05$). Serum glucose levels were substantially higher in the RPO and PKO diet groups than in corn oil and RBDPO groups ($p < 0.05$). AOM treatment showed no significant effect on serum glucose levels in any of the groups ($p > 0.05$). However, certain dietary bioactive substances (phenolic bioactive enriched plant foods) may help improve glycemic management by modulating glucose levels (Sarkar et al., 2022). It is essential to identify possible dietary components that alter glycemic control for both diabetes therapy and prevention.

Corn oil diet resulted in the lowest blood triglyceride levels in both AOM and non-AOM groups (Table 4). Corn oil consists primarily of acylglycerols and a fatty acid composition of 59% polyunsaturated, 24% monounsaturated, and 13% saturated. Linoleic acid (C18:2n6) is the major PUFA, with a trace of linolenic acid (C18:3n3) providing 83 values of n6/n3 ratio. It also contains a substantial amount of gamma-tocopherols (vitamin E) and a high concentration of ubiquinone. These high amounts of PUFA and vitamin E play a role in the health benefits associated with corn oil intake, particularly in lowering triglycerides (Si et al., 2014). In comparison, palm oil-based diets (RBDPO, RPO, and PKO) resulted in lower blood triglyceride levels than beef tallow diets ($p < 0.05$).

The diets containing corn oil and RBDPO resulted in the lowest blood cholesterol levels in both AOM and non-AOM groups (Table 5). The results were similar to

Table 2. The body weight of rats (g) at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	$385±3^{a}$	$306±3^{c}$	$313±6^{bc}$	$323±3^{b}$	$309±10^{c}$
Non-Azoxymethane	$406±5^{a}$	$323±3^{b}$	$333±9^{b}$	$331±8^{b}$	$320±2^{b}$

Values are mean ± S.E.M., $n = 3$. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

Table 3. Glucose levels (mg/dL) in blood serum at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	$130.5±2.8^{a}$	$81.3±0.8^{c}$	$87.6±2.0^{c}$	$101.9±0.7^{b}$	$101.0±0.8^{b}$
Non-Azoxymethane	$126.1±3.1^{a}$	$82.5±1.7^{d}$	$89.1±0.6^{cd}$	$98.2±2.9^{bc}$	$101.4±1.1^{b}$

Values are mean ± S.E.M., $n = 3$. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

Table 4. Triglyceride levels (mg/dL) in blood serum at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	121.6±1.7^{a}	87.3±0.7^{c}	95.4±1.7^{b}	100.8±0.4^{b}	100.1±0.7^{b}
Non-Azoxymethane	124.4±1.0^{a}	88.3±0.4^{d}	96.2±0.8^{c}	101.5±1.0^{b}	101.8±1.2^{b}

Values are mean ± S.E.M., n = 3. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

Table 5. Cholesterol levels (mg/dL) in blood serum at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	158.4±2.7^{a}	107.5±1.1^{c}	108.7±2.3^{c}	130.1±1.8^{b}	131.7±1.5^{b}
Non-Azoxymethane	154.1±2.6^{a}	106.8±2.2^{c}	107.2±1.1^{c}	128.3±1.1^{b}	128.6±0.6^{b}

Values are mean ± S.E.M., n = 3. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

Table 6. HDL levels (mg/dL) in blood serum at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	34.5±0.9^{d}	72.5±2.3^{a}	60.5±1.7^{b}	48.8±1.0^{c}	48.1±3.1^{c}
Non-Azoxymethane	34.8±1.4^{d}	70.7±1.5^{a}	59.0±2.4^{b}	44.2±0.9^{cd}	49.8±2.8^{bc}

Values are mean ± S.E.M., n = 3. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

Table 7. LDL levels (mg/dL) in blood serum at the conclusion of the study

Dietary treatment	Beef tallow	Corn oil	Refined bleached deodorized palm oil	Red palm oil	Palm kernel oil
Azoxymethane	62.8±0.8^{a}	28.6±1.2^{d}	35.5±1.4^{c}	43.0±1.7^{b}	41.5±1.0^{b}
Non-Azoxymethane	65.3±0.4^{a}	28.5±1.0^{d}	35.4±1.0^{c}	42.2±0.8^{b}	40.6±0.8^{b}

Values are mean ± S.E.M., n = 3. ^{a,b,c,d} Different in superscript letter in the same line (same row) indicate significantly different at $p < 0.05$.

previous studies showing that corn oil decreased overall cholesterol. This impact is attributed to the levels of PUFA in corn oil, corroborated by studies showing that corn oil decreases cholesterol. Additionally, the plant sterol content in corn oil (128 mg/1000 kcal) could decrease cholesterol absorption from the gut, lowering body pools and increasing synthesis rate by de-suppressing the activity of cellular hydroxy-methylglutaryl-CoA reductase, positively affecting cholesterol levels (Si et al., 2014). Serum cholesterol was highest in rats fed beef tallow, followed by PKO and RPO ($p < 0.05$).

Blood serum of rats given corn oil diet had the greatest level of HDL, followed by RBDPO, PKO, RPO, and beef tallow diets, respectively (Table 6). RPO produced considerably more HDL than beef tallow in AOM group, which was not observed in Non-AOM group ($p < 0.05$).

Beef tallow diet resulted in the highest level of serum LDL followed by RPO, PKO, RBDPO, and corn oil diets, respectively (Table 7). There were no significant differences between RPO and PKO diets, while the other diet groups showed significant differences ($p < 0.05$). Several fatty acid profiles of vegetable oils (palm oil and corn oil) compared to beef tallow is shown in Table 8.

This study aimed to investigate the impact of consuming various types of fat on biochemical parameters such as blood glucose, TG, TC, HDL, and LDL cholesterol. The changes in glycemic parameters resulted from an impairment in insulin metabolism due to failure to adjust to the damage caused by high-calorie intake from a high-fat diet (HFD) from beef tallow. This leads to deteriorated insulin function and insulin resistance (N'guessan et al., 2022). Furthermore, consumption of other fats may be beneficial, rather than harmful, for long-term glycemic management by keeping blood glucose levels stable (Dhanasekara et al., 2022). A high-fat diet promotes lipid buildup in the muscles, affecting glucose metabolism—both oxidation and glycogen deposition. The results show that serum glucose levels significantly reduced after consuming a palm oil-fortified diet, stressing the role of tocotrienols in decreasing serum glucose levels. Tocotrienols function by acting as peroxisome proliferator-activated receptor (PPAR) modulators and regulate the expression of numerous genes related to energy metabolism (Szulczewska-Remi et al., 2019). Although dietary fatty acids have been related to changes in glucose metabolism and insulin sensitivity, there are still limited information regarding the effects of palm oil consumption to the indicators of the glucose metabolism (Zulkiply et al., 2019).

Serum TG levels have been found to rise due to beef tallow consumption. High TG levels can affect endothelial cells, resulting in noncommunicable illnesses such as CVD. It was also proven that dietary fat enhanced TG levels through hydrolysis of lipoprotein lipase triacylglycerol, resulting in higher liver concentration of TG. Furthermore, dietary fat has been observed to boost phospholipid production by decreasing phospholipase activity or increasing phospholipid turnover as a result of initiating the inflammatory process (Al-Hayder et al., 2020). On the contrary, consumption of PUFA and various bioactive chemicals present in vegetable oils, such as carotenoids and tocopherols, might reduce the prevalence of heart illnesses by lowering TG levels (Al-Hayder et al., 2020; Syarifah-Noratiqah et al., 2020). Hypertriglyceridemia develops when serum TG concentrations rise above normal levels and increases the risk of CVD such as atherosclerosis and myocardial infarction (Mancini et al., 2015). Previous studies showed the safe use of palm oil and palm olein by significantly lowering TG, implying the potential for treating hypertriglyceridemia (Syarifah-Noratiqah et al., 2020). Serum TG level is an essential measure for assessing fatty acid accumulation in adipose tissue and the liver (N'guessan et al., 2022).

The inclusion of saturated and monounsaturated fatty acids in beef tallow explained the increased cholesterol levels in rats fed the diet (Al-Hayder et al., 2020). However, it was established that the consumption of PUFA contained in vegetable oils, such as PKO and RPO, reduced the occurrence of heart illnesses by reducing cholesterol levels (Al-Hayder et al., 2020). There was no significant difference in

Table 8. The profile of fatty acids from palm oil and corn oil compared to beef tallow

No	Sample	Saturated fatty acid	Content (%)	Unsaturated fatty acid	Content (%)	Reference
1	RBDPO	Palmitic acid	42.5-48.5	Oleic acid	35.2-41.7	(Absalome et al., 2020; Hasibuan, 2012)
		Stearic acid	4.1-4.8	Linoleic acid	7.7-11.8	
		Arachidic acid	0.9-1.5			
2	RPO	Palmitic acid	39.2-46.3	Oleic acid	36.7-44.1	(Absalome et al., 2020; Edem, 2002)
		Stearic acid	3.7-5.5	Linoleic acid	8.7-12.5	
		Myristic acid	0.8-1.5			
3	PKO	Lauric acid	45.7-48.2	Oleic acid	15.4-18.2	(Urugo et al., 2021; Sujadi et al., 2016)
		Myristic acid	15.5-17.3	Linoleic acid	2.4-3.0	
		Palmitic acid	8.4-8.9			
		Stearic acid	1.9-2.4			
4	Corn oil	Palmitic acid	8.3-12.6	Oleic acid	23.5	(Dupont et al., 1990; Carrillo et al., 2017; Hwang, 2009)
		Stearic acid	2.0-2.5	Linoleic acid	52.7-59.8	
		Total SFA	10.8-12.7	Linolenic acid	1.1-1.3	
				Total PUFA	58.7-61.1	
5	Beef tallow	Palmitic acid	24.9-29.8	Oleic acid	34.2-36.0	(Ockerman and Basu, 2014; Hwang, 2009)
		Stearic acid	18.9-23.3	Linoleic acid	2.7-3.1	
		Myristic acid	2.3-3.7			
		Total SFA	55.4			

RBDPO- refined bleached deodorized palm oil; RPO- red palm oil; PKO- palm kernel oil; SFA- saturated fatty acids; PUFA- poly-unsaturated fatty acids cholesterol levels between corn oil and RBDPO diet groups. RBDPO, which is high in saturated long-chain fatty acids, particularly palmitic acid, and carotenoids, is expected to prevent arteriosclerosis, limit cholesterol production, platelet aggregation, and lower blood pressure (Szulczewska-Remi et al., 2019). Scientists validated the impact of palm oil on TC reduction and identified it as a significant source of beta-carotene and alpha-tocopherols (Syarifah-Noratiqah et al., 2020; Szulczewska-Remi et al., 2019). Palmitic acid as the dominant saturated fat in palm oil, is considered to have a lesser effect on total cholesterol and LDL-cholesterol in blood, associated with numerous pathological processes in the cardiovascular system (Urugo et al., 2021). Palm oil benefits the body by lowering blood pressure and platelet thrombosis while protecting the liver from oxidative damage (Edem, 2002).

The β-carotene in palm oil may be useful in correcting vitamin A deficiency (a public health issue in many underdeveloped nations) as well as protecting against some types of cancer. Based on the results, palm oil (at modest levels) is entirely safe and non-toxic, easily digested, quickly utilized, and well absorbed. It is a highly stable and good quality oil that does not contain Trans fatty acids. In addition to lowering the incidence of CVD, palm oil is carcinogen-protective and rich in β-carotene, which can reduce nutritionally induced blindness. Tocotrienols are found in higher concentrations in palm oil than in many other oils, and suppress cholesterol production, platelet aggregation, and prolong the lives of malignant animals (Edem, 2002).

Previous studies established a link between dyslipidemia and low HDL cholesterol levels. HDL cholesterol is referred to as "good cholesterol" since it assists in the removal and recycling of cholesterol through the liver. Therefore, HDL cholesterol protects the inner blood vessel walls and helps prevent noncommunicable diseases such as dyslipidemia (Al-Hayder et al., 2020). The favorable effect of palm oil observed in this study is consistent with previous studies (Amini et al., 2017) and a recent meta-analysis (Wang et al., 2019), showing that palm oil intake increases HDL concentration.

LDL cholesterol is associated with an increased risk of CVD and commonly referred to as "bad cholesterol" (Al-Hayder et al., 2020). Consuming lard elevated non-HDL cholesterol concentrations, including LDL fraction, a well-known CVD risk factor. This is consistent with studies showing that saturated fat increases LDL cholesterolemia. The atherogenic index of plasma is another essential metric for cardiovascular health and has values inversely related to lipoprotein particle size, showing atherogenicity in humans (Jurgoski et al., 2014). Tocotrienols in palm oil play a key role in degrading total and LDL cholesterol by decreasing the hepatic enzyme 3-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase. This enzyme is responsible for cholesterol production through a post-translational process (Szulczewska-Remi et al., 2019). It was reported that tocotrienol in palm oil decreased serum LDL level by 7-38% without affecting HDL levels (Urugo et al., 2021). The results were consistent with previous study, showing that palm oil consumption maintains the ideal levels of cholesterol, HDL, triacylglycerols (TAG), and TC in humans when compared to other vegetable oils (Dian et al., 2017; Nagendran et al., 2000; Syarifah-Noratiqah et al., 2020).

This study shows that feeding palm oil to rats is beneficial to serum glucose and lipid profile (TC, HDL-C, LDL-C, and TG), compared to animal-based fat (beef tallow). Additionally, despite the refining process that could remove some bioactive components (tocotrienols, tocopherols, and carotenoids), RBDPO showed better results than RPO and PKO. The results from RBDPO group were closest to the results from corn oil, which was also refined in this study. Nagendran et al. (2000) showed that RBD process eliminated carotenoids (from 513 ppm in RPO to nil ppm in RBDPO) and decreased vitamin E (from 707 to 561 ppm). However, RBDPO and corn oil in this study were enriched by the manufacturer with vitamin E (10%). An advanced refining process that retains most of the carotenoids could have also been implemented by the manufacturer. Hasibuan et al. (2021) stated that RBDPO retained carotenoid values (189 ppm) compared to RPO (250 ppm). These factors explain why the outcomes for RBDPO group are similar to or better than those for RPO and PKO.

CONCLUSION

In conclusion, beef tallow, mainly composed of saturated fatty acid, affected blood glucose and lipid levels. However, vegetable oils containing unsaturated fatty acids and bioactive substances, such as corn oil, RPO, PKO, and RBDPO, were shown to be effectively metabolized with less impact on blood glucose and lipid levels. Based on this study, fat source affects blood glucose and lipid profiles. However, there were limitations due to the number of rats used. Further studies are required to validate these results and assess the potential benefits of palm oil consumption on health, particularly regarding serum glucose and lipids profile.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in the publication of this manuscript.

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