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TOXICITY OF REUSED COOKING OIL: A REVIEW

Khadijah Nabilah Mohd Zahri[1], Azham Zulkharnain[2] and Siti Aqlima Ahmad[1*]

[1]*Department of Biochemistry, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, UPM 43400 Serdang, Selangor, Malaysia*
[2]*Department of Bioscience and Engineering, College of Systems Engineering and Science, Shibaura Institute of Technology, 11 307 Fukasaku, Minuma-ku, Saitama, 337-8570, Japan*

*Corresponding Author: aqlima@upm.edu.my

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Abstract

Repeated heated cooking oil has been a regular practice to save cost and people believe that vegetable oil was the best choice of cooking oil since it has functional and nutritional benefits to consumers such as high vitamin and antioxidant content. However, the consumption of reused vegetable oil could give harmful effect on body cells. Repeatedly heated vegetable oil can produce other harmful compounds or by-products with the potential risk to human body systems, such as volatile compound (alcohol, aldehyde, and ketone), polar compound (monoacylglyceride, diacylglyceride, and glycerol), non-polar compound (trans-fatty acids) and toxic compound (acrylamide). These molecules were resulted from several reaction processes from heating including the process of hydrolysis, oxidation (oxidative decomposition, oxidative haemolytic cleavage, and millard reaction), cyclisation, isomerisation and polymerisation of oil. Formation of free radicals can cause oxidative stress and accelerate degradation of lipid. In addition, high temperature to the cooking oil could alter the antioxidant molecule function. Plus, fried food from reused cooking oil is able to change the nutritional content in food itself; for example, vitamins (E, A, B and C) and mineral component. This activity can lead to increase blood pressure, total cholesterol low-density lipoprotein (LDL), saturated fatty acid and eventually cause atherosclerosis, hypertension, neurodegenerative and even cancer. This review studies the adverse effect of repeated heated vegetable oil intake towards human and aims at increasing the awareness of the community around the world.

INTRODUCTION

Cooking oil is widely used around the world in the food industries and especially in the household kitchen daily. According to Kumar et al. [1], industry sectors such as food processing, dairy, bakery and beverage industries as well as the kitchen activities are the major doings that lead to pollution particularly oil as the pollutants. Furthermore, Cao et al. [2] stated that public restaurants also contribute to the consumption of cooking oil, either vegetable or fish oil. The chemical composition of this type of lipid consists of saturated or unsaturated fatty acids and glycerides. At the same time, cooking oil acts as a medium in heat and mass transfer between foods and oil [3]. In addition, they stated that vegetable oil is the majorly used by consumers around the world due to its properties that comprise unsaturated fatty acid and free cholesterol compared to the other types of cooking oil.

Cooking oil is an essential part of a healthy diet, where a small intake of fatty acids (FAs) helps the body to absorb the fat-soluble vitamins; A, D, E and K [4]. Several benefits of the cooking oil were reported, which include the fats have high energy value, can act as precursors of biologically active compounds of the body and function as constituents of the cell membrane and body fluids [4]. As Kumar et al. [5] mentioned that FAs also give benefits to human health such as the FAs was proven able to help in growth and embryonic development, human brain function, also for therapeutic and preventive healthcare.

Globally, the market for cooking oil is growing with the increased consumption of oil increasing each year. Ismail et al. [6] mentioned that about 70% of the global volume of the cooking oil is produced with the four largest producers; Russia, Ukraine, Europe and Argentina. The problem occurred when households and certain industries sectors repeatedly heated their cooking oil resulting in 0.5 million tonnes of waste cooking oil (WCO) discarded in Malaysia annually [7]. There was a survey by Azman et al. [8] presented that, for 63% of the respondents consisting of night market food outlet operators in Kuala Lumpur, Malaysia, admitted that they used cooking oil repeatedly. These activities cause the disposal of untreated WCO into the environment and wastewater thereby leading to pollution. A minimum amount of waste oils and greases in sewage can foul wastewater treatment plants, resulting in increased maintenance costs and decreased treatment efficiency [9]. WCO was categorised as pollutants since the repeated heated of cooking oil can cause toxicity to the organisms in the environment. Furthermore, the WCO can cause blockage in the pipe and lead to odour pollution [10].

Although vegetable oil has been considered as the healthiest cooking oil due to its nutritional value [11], the vitamin in the cooking oil can be oxidised when the temperature of the oil reached the range of 70°C to 90°C [12]. They also mentioned that the changes of macromolecules for instance protein, carbohydrate and mineral component of the deep-fried food occurred can lead to a chemical reaction that allows the production of harmful by-products such as aldehyde and acrylamide. Okino-Delgado et al. [13] revealed that the heated vegetable oil will cause the healthy oil (room temperature) to become toxic at a certain degree of temperature. Repeated heated WCO can cause dietary contamination and health adverse effects such as cancer, cardiovascular disease and atherosclerosis, which can also damage genetic information inside the cells [14]. The toxicity of the WCO needs to be understood and the level of knowledge of people around the world needs to be increased so that the disposal of untreated WCO into the environment can be prevented.

Uses of vegetable oil in industry that contribute to the production of WCO

There are three categories of activity with different characteristics of vegetable oils [15]. First, most companies in frying industries use a continuous frying system because it is easy to control compared to a discontinuous system where some of small or medium-sized enterprises also prefer this way than the other. Second, in large caterings or restaurants have the largest proportion of reused oil waste production. Lastly, small restaurants or bars create a fair amount of the total of cooking oil waste. Different countries have different cultures in recycling vegetable oil, which can contribute to the production of waste and can cause pollution and toxicity to the environment as well as other organisms.

Effect reused cooking oil

Various chemical changes happened through the exposure of high temperatures from the deep-frying method. Additionally, frying is an early and popular way of cooking throughout the world [16]. Frying operation allows the oil to be absorbed in food by 5% to 35% by weight and the fat component can be released into the frying oil [17]. This can lead to physiochemical changes; thus, the implications from the consumption of repeated heated cooking oil to human health need to be understood. **Table 1** shows the physicochemical changes of heated cooking oil properties.

Atherosclerosis

Atherosclerosis is progressively increased by oxidative stress and chronic inflammation, which can cause other diseases including endothelial dysfunction, plaque formation that can lead to coronary artery disease (CAD) and diabetes [2]. Adam et al. [24] stated that high cholesterol level and high LDL from oxidation of saturated fatty acid are the main causes of atherosclerosis disease, while Ganesan et al. [25] summarised that atherosclerosis is caused mainly by raised serum total cholesterol (TC) and triglycerides (TG), increased platelet aggravation and fibrinogen. Several studies reported that the inflammation from reactive oxygen species ROS production due to the repeated heated cooking oil increases the expression of inflammatory biomarkers identified as risk factors for cardiovascular diseases including atherosclerosis [20].

Vegetable oil oxidation reaction include enzymatic oxidation, thermal oxidation, photo-oxidation, and auto-oxidation involved the formation of free radicals, ROS, peroxide groups and cyclic monomer [26, 27]. Oxidative stress arises with the presence of ROS where these free radicals react with nitric oxide (NO) and lead to the production of unstable isomer of nitrate that promotes the chain of lipid [28]. The free radicals play a significant role in LDL oxidation and promote the progression of other diseases including atherosclerosis [14, 25]. Generally, high oxidative stress causes high ROS production and damages or oxidizes other macromolecules including the protein and lipid in the body cells.

According to Ng et al. [28], the oxidative decomposition reaction from lipid oxidation produces aldehyde as a key product, which helps in increasing the expression of CD36 that can cause atherogenesis. CD36 plays a role as an atherosclerosis biomarker; for instance, Febbraio et al. (2004) injected the mice with macrophages with CD36 and found that the atherosclerotic lesion area was increased compared to the mice without the presence of CD36 [29].

According to Conklin [30], inhalation of aldehyde can be worsened with a high level of amount, which can further cause pulmonary irritant effects and injury, cardiac and vascular effect. Usually, the presence of aldehyde in high temperatures involved acrolein in a gas weapon such as during World War I for wildfires due to its high chemical reactivity.

Atherosclerosis disease can be measured through the level of serum LDL in the blood body. Adam et al. [24] tested the heated cooking oil into the ovariectomized rats and discovered that serum LDL was increased compared to the fresh cooking oil and according to Heinecke [31], the oxidation of LDL induced the atherosclerosis disease by certain reactions.

dysfunction is triggered by oxidative stress and provokes inflammatory processes through the activation of transcription factors [28]. High ROS production in vascular wall and decreased bioavailability of NO produce endothelial dysfunction due to the ROS that could damage cell lipids [18, 20, 25]. At the same time, Ng et al. [28] also reported that the mechanism of endothelial dysfunction is a reduction in NO availability, which resulted from the reduced production and increased breakdown of NO causing the lipid peroxidation process to take place.

Other than endothelial dysfunction, inflammation can also cause atherosclerosis, due to the increasing number of inflammatory biomarkers during high temperature of cooking oil. For example, C-reactive protein (CRP), which is one of the biomarkers that induce inflammatory changes in the body [20].

Table 1. Effect in physiochemical of heated vegetable oils

Vegetable oil	Diet formulation	Subject	Duration	Physiochemical changes									References
				BP	PV	AV	BW	TG	TC	LDL	HDL	Other remarks	
Palm oil (10 frying cycle)	15% w/w	Sprague-Dawley rats (200-280 g)	6 months	-	-	-	-	-	↑	↑	-	Plasma TBRS ↑ ACE activity ↑ HO↓	Leong et al. [18]
Canola oil (10 frying cycle)	7% w/w	Wistar rats (300-330 g)	10 weeks	↑	-	-	↑	-		-	-	Glucose plasma ↑ Vasodilation ↑	Bautista et al. [19]
Virgin coconut oil (5 and 10 frying cycle)	15% w/w	Sprague-Dawley rats (200-250 g)	4 months	↑	↑	-	-	-	-	↑	-	Plasma TXB_2 ↑ Plasma VCAM-1↑ Plasma ICAM1↑ Plasma CRP ↑ Plasma PGI_2 ↓	Hamsi et al. [20]
Palm oil	20 tpo	Wistar strain albino rats (40-50 g)	30 days	↑	-	-	-	-	↑	↑	↓	Total protein ↓	Falade et al. [21]
Arachis oil (through assay)	-	-	Heated for 20 min at 220°C)	-	↑	↑	-	-	-	-	-	MDA content ↑ Total carotenoid ↓ Iodine value ↑	Falade and Oboh [22]
Palm oil	10 ml oil/kg	Wistar rats (160-190 g)	28 days	↑	-	-	-	↑	↑	↑	↓	AI↑ CVRI index↑ CRI index↑	Famurewa et al. [23]

Symbol indicate: ↑(increased);↓ (decreased); - (no data)

Abbreviations: BP (blood pressure); PV (peroxide value); AV (acid value); BW (body weight); TG (triglycerides); TC (total cholesterol); LDL (low density lipoprotein); HDL (high density lipoprotein); TBSR (thiobarbituric acid reactive substances); ACE (angiotensin-converting enzyme); HO (hemeoxygenase); TBX_2 (thromboxane); VCAM-1 (vascular cell adhesion molecule); ICAM-1 (intercellular adhesion molecule); CRP: (C-reactive protein); PGI_2 (prostacyclin); MDA (malondialdehyde); AI (atherogenic index); CVRI (cardiovascular risk index); CRI (coronary risk index); w/w (weight/weight).

Inflammation and endothelial dysfunction

According to Leong et al. [3], endothelial dysfunction is associated with abnormal endothelium-dependent relaxation where the endothelial cell can respond to chemical and physical signs that control the metabolism reaction in vascular tone, cellular adhesion, platelet clumps, smooth muscle cell multiplication and inflammation. Endothelial

Other than atherosclerosis, hypertension disease can also be triggered in the presence of those inflammatory biomarkers since it has been identified as among the risk factors for cardiovascular.

Meanwhile, high ratio N-6 fatty acid (pro-inflammation) in cooking oil can cause the inflammation of joint and surrounding tissues induced to the autoimmune disease, which is rheumatoid arthritis (RA) [32]. Most vegetable oils have a high ratio of N-6 fatty acid compared to N-3 fatty acid. Plus, heated N-6 fatty acid cooking oil can induce oxidative stress and lead to inflammation.

High blood pressure

An increase in blood pressure is affected by heated oil that attribute to the oxidative stress, where Hamsi et al. [20] reported that virgin coconut oil has led to an increase in blood pressure after repeatedly heated the oil than other types of vegetable oil, which were palm oil and olive oil. Leong et al. [3] reported that oxidative stress from the oxidation of repeated heated cooking oil especially N-6 polyunsaturated fatty acid (PUFA) was able to elevate the vascular activity and blood pressure. Prostacyclin (PGI2) and Thromboxane A2 (TXA2) function in regulating blood pressure levels in the body and amplifying platelet aggregation, respectively. However, repeatedly heated cooking oil can disrupt both hormone levels where the ratio for TXA2/PGI2 was is increased thus increasing the blood pressure in organisms [28, 33].

According to Hamsi et al. [20], vascular cell adhesion (VCAM-1) and intercellular adhesion molecule (ICAM-1) expression have a significant correlation with blood pressure disease in reheated cooking oil. Most studies discovered that the expression of these molecules increase after consuming heated cooking oil [20, 33-35]. Ng et al. [28] stated that the consumption of heated cooking oil raised plasma angiotensin-converting enzyme (ACE) that allowed the activation of angiotensin I (Ang I) to potent Angiotensin II (Ang II) the vasoconstrictor by narrowing the blood vessel, which resulted in increased blood pressure.

Several studies in animals including rats have been conducted, which reported that the arterial blood pressure and plasma lipid profile of rat have significantly increased compared to the control and non-heated cooking oil [33]. In another study, the rats were introduced with repeatedly heated palm kernel oil showing an increased number of serum TC and TG and eventually an increased in blood pressure [23]. Meanwhile, Leong et al. [36] conducted a study on heated palm oil (HPO) and found an increment of 24% to and 30% in blood pressure for 5HPO and 10HPO, respectively, for 24 weeks.

Hypertension

There was a study reported that repeated heated vegetable oil had given a positive association with the risk of hypertension [2, 3]. Uncontrolled production of ROS altered the metabolism reactions in the human body including transcription factors and disrupted the translation process leading to the endothelial dysfunction associated with hypertension disease [37, 38]. The production of ROS from vascular endothelium under pathological conditions can cause the pathogenesis of hypertension [37].

Moreover, high blood pressure and lipid peroxidation reaction from repeated heated vegetable oil can contribute to the development of hypertension [14, 39]. Cardiovascular disease caused by oxidative stress and chronic inflammation may lead to various heart-related diseases. For example, hypertension, congestive heart failure, hardened arteries, myocardial infarction (heart attack) and circulatory system disease [25].

The disruption of hormonal balance such as prostacyclin (PGI2) and thromboxane A2 (TXA2) hormones can promote hypertension disease [20]. Ng et al. [33] studied the effects of repeatedly heated soybean oil to Sprague-Dawley rats for 6 months where they fed the rats with fresh soybean, five-time-heated soybean oil (5HSO) and ten-time-heated soybean oil (10HSO). They found that PGI2 and TXA2 were decreased, which might increase the oxidative stress. Furthermore, VCAM-1 and ICAM-1 expressions were increased in 5HSO and 10HSO-fed rat showing the possibilities of hypertension disease due to the increase in blood pressure [33].

Carcinogenicity and genotoxicity

Numerous studies in humans and animals have been done to determine the carcinogenicity and genotoxicity of reused cooking oil. Ganesan et al. [40] listed the in-vitro and in-vivo effects of reheated cooking oil for various types of deep-fried vegetable oil in different models. High consumption of fried food could lead to malignancies such as lung cancer, breast cancer, colorectal cancer and prostate cancer [32, 41]. Oxidative stress from the chemical reaction is one of the contributing factors of carcinogenesis, where one of the factors that happened from the PUFA cooking oil type. According to Chaturvedi et al. [32], most of the cooking oil are PUFAs that might cause inflammation when introduced to high temperature. Some of PUFAs derivatives like prostaglandins (PGE2) have been linked with breast cancer, which increased the expression of mRNA in synthesizing the estrogen from androgens.

The thermal oxidation process at 170°C to 220°C can lead to the production of polycyclic aromatic hydrocarbons (PAHs) that affect the protein, DNA, RNA and lipid structure, which can potentially cause the disruption and destruction of cell and membrane injury, chromosomal disorder and production of harmful compound [38, 40, 42]. According to the study, PAHs are responsible for genotoxic and can act as an inducer for the mutation resulting in cancer. This has been proven by the International Agency for Research on Cancer, where they classified some PAHs as known, possibly, or probably carcinogenic to humans. This toxic compound can be absorbed through various routes in mammals including inhalation, dermal contact and ingestion. The most significant health effect to be expected from inhalation exposure to PAHs is the excess risk of lung cancer [43].

Extensive studies on the toxicity of repeated heated cooking oil have been conducted including the risks of the cooking oil fumes (COFs) to human health. Lee and Gany [44] stated that lung cancer has been reported to be related to COFs where they presented occupational type as one of the factors contributing to the risk of lung or cervical cancer. The household and occupational exposure such as chef and cook have been found significantly associated with a high risk of large cell carcinoma (lung). CFOs containing aldehydes, PAHs and acrolein as well as the fumes from high-temperature frying cooking oil are categorised as group 2A [45]. Acrolein is a highly reactive unsaturated aldehyde that can exert harmful effects on the human body such as myocyte dysfunction, myocyte necrosis and apoptosis [46]. On the other hand, Dung et al. [47] examined the formation of mutagenic compounds in fumes of heated vegetable oil and reported the presence of alkenyl mutagenic compounds that affected the respiratory tract, showing that the oil fumes were able to damage cellular DNA and led to cancer.

At the same time, oxidative stress and inflammation were identified as among the factors in the formation of cancer where the methylation reaction in cells took place. Heated cooking oil increases the TC and can lead to cholesterol oxidation. Moreover, a researcher stated that the compounds produced from oxidised cholesterol were reported to be cancer-causing, mutagenic and cytotoxic [17]. The frying or baking process of mainly potato and cereal-based products leads to the production precursors of carcinogens such as acrylamide, furan, and 4-hydroxymethylfurfural (HMF) [17]. Stevens and Maier [48] mentioned that the emission of acrolein from heated oil in wok pan has been linked to increasing the occurrences of lung cancer in Chinese women, which was claimed to have toxic effects either through inhalation, ingestion and skin contact. Besides, acrolein is able to affect various locations in the human body such as lipids, blood vessels, myocardial ischemia and infraction as well as lead to other diseases including cardiomyopathy [46].

The risks have been proven by Wistar rats through the introduction of repeatedly heated coconut oil, resulting in increased aberration, micronuclei induction and cytotoxicity as well as altered hepatic [49]. According to the Ishii et al. [50] acrylamide can exert genotoxic potential in carcinogenic target sites of mice and induce neurological abnormalities of mice. There a study reported that acrylamide can cause chromosomal aberrations and injury to the central nervous system [51].

Neurodegenerative disease

Several studies claimed that consuming the heated cooking oil can cause human neurodegeneration, which is caused by the progressive deterioration or death of nerve cells. Human neurodegenerative diseases include Alzheimer, multiple sclerosis, Huntington's disease, and Creutzfeldt-Jakob disease [52]. The production of a by-product from chemical reaction in repeatedly heated cooking oil such as aldehyde can cause brain diseases like neurodegenerative disease (Alzheimer disease). In addition, Alzheimer's disease has been reported to be related to 4-hydroxy-trans-2-nonenal (HNE), which changes the structure of corticol synaptosomal membrane proteins and neurotoxic [38, 53].

The role of HNE in health and disease has been reported previously by Csala et al. [53] including the relationship of HNE and Alzheimer's disease where HNE acts as an effector for aβ-induced free radicals. Moreover, it can alter cellular signalling through alkylation chemistry that can cause multiple central nervous system (CNS) diseases including Alzheimer's and Parkinson's diseases [54]. According to Schaur et al. [55], oxidative stress is associated with the pathogenesis of disease, leading to oxidative alterations of cellular macromolecules including the increased formation of HNE. HNE that is found covalently bound with another protein called multidrug resistance protein-1(MRP1) in Alzheimer's disease (AD) brain in high amount can lead to neuronal cell death.

Diabetes and obesity

Deep fat frying increases the total fat content and has been associated with obesity and type 2 diabetes [12, 56]. Chaturdevi [32] stated that obesity induces oxidative stress and inflammation, which furthers causes leukotriene (LTB4) induced insulin resistance and leads to type 2 diabetes disease. LTB4 is a lipid mediator as Li et al. [57] claimed that it is a pro-inflammatory lipid mediator that can immediately promote less insulin sensitivity in myocytes and hepatocytes. Other inflammatory mediators produced from repeatedly heated cooking oil are tumour necrosis factor-alpha (TNF-α) and Interleukin-6 (IL-6) that also involved in inflammation in the pathogenesis of type 2 diabetes [32].

There has been a study conducted using 84,555 women in the Nurses' Health Study in the United States of America (USA), where Halton et al. [58] investigated the relationship between fried food consumption and the risk of type 2 diabetes. From the study, the French fries showed a positive association with the risk of type 2 diabetes, which may be due to the partially hydrogenated oils containing trans-fat. There were also other studies investigating the association between vegetable oil and fried food consumption incident type 2 diabetes [59-61].

CONCLUSION

Based on the information discussed above, repeatedly heated cooking oil will alter the physical and chemical properties of lipids. Since cooking oil is a common medium used for frying, baking and boiling throughout the world, the risks from consuming repeatedly heated oil pose an important general health problem. The consumption of food containing heated cooking oils could be harmful in cardiovascular system function and induce some risk factors of diseases such as atherosclerosis, high blood pressure and hypertension. By taking it blindly as a daily routine, there is a possibility of developing endothelial dysfunction, neurodegenerative, diabetes and even cancer. To avoid any serious health threats, it is advisable not to reheat cooking oil several times at home and take less fried food from outside. It is also recommended that all food industries, restaurants and food stalls take this problem as a serious matter and not to recycle their cooking oil only to save the costs and consider changing the habit for better health. The important role of vegetable oil that provides a health benefit to the human body should be retained by not reheating or recycling the cooking oil with high temperature, as vegetable oil poses antioxidant activity and contains ascorbic acid, carotenoids, tocopherols and polyphenols. Plus, it also has an anti-obesity effect, cardioprotective effect, as well as anti-aging potential, and anti-inflammatory potential.

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