

Chemical Change in Palm Oil during Frying with Deep Fat Frying Method

Halimah¹, HanifahNuryani Lioe^{2*}, RatuAyuDewi Sartika¹



¹Public Health Science, Faculty of Public Health of Universitas Indonesia, Depok 16424

²Department of Food Science and Technology, Faculty of Agricultural Technology,
IPB University, Dramaga, Bogor 16680

Abstract— Food processing with deep fat frying method with palm oil has been frequently made either by restaurants, caterings, or food industries in Indonesia. It has been identified that the frying process with high temperature and long frying duration is the cause of the oil damage. The objective of this review is to describe the chemical change in palm oil during the frying process with deep fat frying method and to evaluate the results of oxidation, hydrolysis, and polymerization reactions during the frying process. The frying temperature between 150-250°C, frying duration until 48-50 hours, and the repeated oil use caused the decomposition of some triglycerides, the composition change of saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA), poly-unsaturated fatty acids (PUFA), and the formation of aldehyde compound, short chain fatty acids, ketone compound categorized as volatile and non-volatile compounds. The evaluation of the oil quality during the frying process taking into account the peroxide, iodine, para-anisidine, free fatty acid values and the percentage of total polar compounds is also discussed in this review. The toxic contaminant compounds due to high temperature frying (in average 180°C) have been formed. They are trans-fatty acids i.e. elaidic (C_{18:1,9t}) and trans (C_{18:2,9C12t/9t12c}). Glycidyl esters compound are formed in palm oil during temperature deodorization process of >230°C. The contaminant concentration reduces during the frying which are observed from some researches. The frying temperature of 150°C-165°C with twice repetition has the lowest trans-fatty acids content. This temperature is recommended to minimize the effects of trans-fatty acids against the health.

Keywords— Palm oil, Frying, Oil evaluation, Trans-fatty acids, Fatty acids composition

1. Introduction

Frying is a cooking method with oil as the heat conductor medium. Food preparation with deep fat frying method is very favourable since it gives delicious taste for the food, besides that the oil can be used repeatedly on different foods. Some studies reported that the frying process is conducted in various temperatures of 150°C-250°C, long duration until 40-50 hours and repeated^{1,2}. The high temperature frying process with oxygen from the air and the water from the food material causes the chemical reactions of oxidation, hydrolysis and polymerization. The chemical process due to the frying process degrades the oil quality since it forms volatile and non-volatile compounds or polar and polymer compounds which are oxidation results of triglycerides³. The oil quality is measured based on the formed iodine, para-anisidine, acids and polar compounds values⁴.

The chemical process of high temperature frying, long duration and repeated use causes the composition change of saturated fatty acids and mono-unsaturated fatty acids in the oil. Besides that, it forms toxic compounds, such as trans-fatty acids in the oil which bring the effects against the health⁵. The frying effects against the concentration of glycidyl esters as contained in fresh palm oil is discussed in this review. This review has the objective to describe the chemical quality of palm oil and the contaminants which are formed during the frying process with deep fat frying method.

2. Chemical Process of Frying with Palm Oil

2.1 Temperature and Duration Effect during Frying

Frying with palm oil as the heat conductor medium with deep fat frying applies the frying temperature of 150-250°C^{1,6-11}. Various studies discuss about frying with palm oil whose frying temperature which is used is 180°C. Frying duration or length of frying duration is varied. Frying duration is the length of oil heating which is used to fry with deep fat frying method. Frying duration is commonly carried out in the range of 2 – 8 hours each day, maximum length of heating can achieve 48-50 hours^{1,6}. The frying for 8 hours can make 48 frying process cycles¹⁰.

During the frying process, there occurs the oxidation result which decomposes unsaturated fatty acids and mono-unsaturated fatty acids. The decomposition results in volatile compounds which determine the quality of cooking oil. Those volatile compounds such as aldehyde, ketone, alcohol, acid and ester compounds¹². Other than volatile compounds, polar compounds of peroxide and free fatty acids groups, dimer, oligomer compounds is also formed as the result of plantation oil heating^{6,13-15}.

Peroxide value of fresh palm oil in the beginning of frying (0 hour) is 5.0 meq O₂/kg of oil. The longer oil heating, the peroxide value is increasingly decreased until the length of heating of 32 hours becomes 2.4 meq O₂/kg which means the amount of peroxide compound is increasingly decreased. Peroxide value increases after 40 hours of frying into 5.3 meq O₂/kg, it is higher than the beginning of frying (0 hour). Peroxide is a primary product of the lipid product with unstable nature that easily experiences decomposition to become other lipid oxidation products¹. The same result is also observed by Cardoso-Ugarte (2013), imitating the frying practice in fastfood restaurants to fry french fries. Length of frying is 200 minutes each day, peroxide value 0 hour which is less than 2.0 meq O₂/kg becomes 12.0 meq O₂/kg after 200 minutes of frying. On the 2nd day of frying, peroxide value decreases into about 11.0 meq O₂/kg and this value is relatively stable until the 5th day of frying.

Free fatty acid is a polar component, such as oleic acid resulted from the triglyceride hydrolysis. Free fatty acid with short carbon chain is a decomposition of hyperoxide in high temperature. Free fatty acid can be analyzed as the percentage of oleic acid. Free fatty acid in fresh palm oil has concentration of about 0.16% (as the oleic acid). During the frying for 8 hours through 48 hours, free fatty acid always increases from 0.36% at 8 hours of oil heating until 1.83% at 48 hours of heating¹. However, it is different to the study of Aniołowska & Kita (2016) which stated that free fatty acid has a negative correlation with temperature and heating time. The higher heating temperature from 150°C to 180°C, the concentration of free fatty acid in palm oil will be more reduced. The longer oil heating (180°C) from 24 hours to 40 hours, the lower concentration of free fatty acid in palm oil; its initial value in fresh oil is 1.58% which becomes 1.16%. It can be caused since not only oleic acid which is formed from triglyceride hydrolysis but also oligomer compounds were resulted so that free fatty acid value in the oil is getting decreased due to the reduction of oleic acid content⁵.

The formation of polar and polymer compounds has been proven more increased in line with the longer time of heating and the increase of heating temperature which causes the oxidation increase of fatty acid in the oil^{1,5,16,17}. The study result of Romano (2012) stated that the concentration of total polar compounds in fresh palm oil of 2.9% will increase until 23.5% (8 times of magnitude) during the heating for 40 hours at the temperature of 180°C. It is pursuant to the study of Aniołowska (2016) which stated that the concentration of polar compound with the temperature of 180°C and duration of 40 hours increases of about 3 times larger

than the concentration of polar compound of the fresh oil, i.e., from 8.96% increased to 22.71%.

2.2 *Frying Repetition Effect*

Based on the market survey and cooking oil distribution, in average households conduct the frying of food material using repeated oil until 4 times with the range of 1-9 times (table 1). The oil use until 2 (twice) of repetition is 61.2%^{18,19}. The chemical change of palm oil is also affected by the frying repetition and type of fried food^{1,10,20}. Frying repetition in this case is using the same oil for frying the material repeatedly. Chemical change in cooking oil is very affected by type of food material, namely material with high hydrocarbohydrate, such as cassava²⁰ and sweet potato^{1,6}, high protein material, such as meat¹⁰ and ruminant animal meat (cow)²⁰.

Concentration of oleic acid reduces in the oil used repeatedly to fry cassava as the material which is rich with carbohydrate. Concentration of oleic acid in fresh palm oil of 41.35% reduces into 35.69% at the 4th frying repetition at the temperature of 200°C. However, the concentration of oleic acid in the oil which is used to fry cow meat experiences the change of oleic concentration which is not constant for each repetition²⁰.

2.3 *Reactions During Frying*

The high temperature frying process causes various chemical reactions in the oil. The occurred chemical reactions, such as oxidation, polymerization, hydrolysis reactions which involve formation and decomposition of hydroperoxide of saturated fatty acids and mono-unsaturated fatty acids, aldehyde, ketone, hydrocarbon, alcohol, and free fatty acids and ester compounds. These reactions result in non-soluble compound, volatile compound which is able to increase viscosity, dark color, foam and hotspot. The formation of volatile compound as the result of hydroperoxide decomposition of most oleic acid oxidation, which is main fatty acid of the palm oil^{4,12}.

Chemical change during frying process is identified through the value change of the oil quality parameters. Oil quality parameters are peroxide value, iodine value, free fatty acids, total oxidation (TOTOX) value, para-anisidine value (p-AV), total polar compounds⁴.

Peroxide Value (PV) becomes the indicator that the oil oxidation has occurred. Determination of hydroperoxide reaction is measured in volumetric by way of preserving potassium iodide reacted with the oil so that it releases iodine. Peroxide value is calculated under milliequivalent oxygen per kg oil (meq kg⁻¹) or ppm⁴. Peroxide is a primary oxidation result of hydroperoxide compound with unstable nature and will be decomposed, and PV value can decrease after the frying. Some peroxide compounds change into another compounds, such as aldehyde compound which cannot be measured in the analysis of peroxide value. In certain circumstances, the formation of peroxide compound is inhibited by the oxygen availability due to oxygen solubility in oil reduces in high temperature. This inhibition is caused by the water comes out from the food which gives the protective layer^{1,21}. The study of Romano (2012) showed that the change of peroxide value in palm oil with different length of heating. PV is more decreased until the length of heating of 32 hours, however, it increases at the length of heating of 40 hours. Peroxide value is higher in the oil for frying compared to the PV of the oil which is heated²¹.

The evaluation of oil stability quality upon the oxidation can be measured with iodine value (IV). Iodine value is the absorbed iodine centigram; the value which shows the number of double bonds in mono-unsaturated fatty acids. The more double bond, the higher iodine value. The higher number of double bonds,

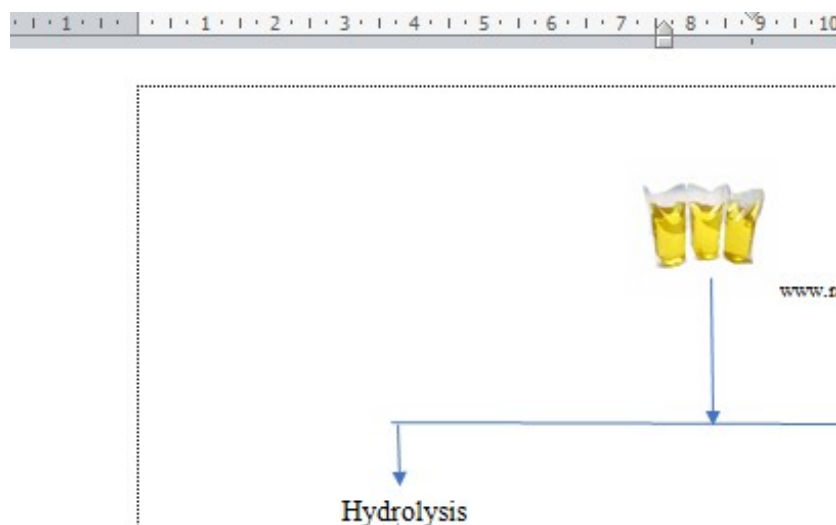
the quicker oil being oxidated, mainly during frying. Decrease of iodine value is positively relative with the decrease of double bond when the oil being oxidated.^{4,16,22}. Potato chips frying for 3.5 hours each day conducted for 5 days is proven to reduce total mono-unsaturated fatty acids significantly showed from iodine value. Iodine value more reduces on the fifth day, fresh palm oil IV of 57.27 becomes 52.81²². According to the study of Arslan (2017), iodine value of pure palm oil (IV 56.95) more reduces in the tenth frying (IV 55.3).

Acid value is the free fatty acid (FFA) value which is measured from total milligram of KOH required to neutralize free fatty acids of 1 gr of oil (mg KOH/g). Acid value is measured under molecular weight of laurate acid with the unit of weight percentage. The longer frying, the acid value will more increase and increase further by the frying repetition. Increase of acid value occurs under the oxidation of fatty acid double bond which forms carbonyl compounds and low molecular fatty acid^{1,4,15,16}. Existence of water in the fried food will hydrolyze the oil forming glycerol compound and free fatty acid which can be measured with acid value²¹. According to the studies of Fauziah (2000) and Arslan (2017), there occurs the increase of acid value in palm oil until 40 hours of frying for five days of potato frying. Acid value of fresh palm oil of 0.77% increases to 1.09% at the the 10th hours of frying. According to the study of Romano (2012), the acid value (oleic acid) experiences the increase until the heating of 48 hours, from 0.16% of fresh palm oil increases to 1.83%. The measuring of acid value is conducted because it is the indicator of oil and food quality based on rancidity and unfavourable flavor due to the cooking oil hydrolysis^{16,21}.

Para-anisidine value (P-AV) is defined as the relative amount of non-volatile mono-unsaturated aldehyde compound which is formed under secondary degradation of fatty acid hydroperoxide. Aldehyde as a secondary degradation product is a compound which is resistant to the heat compared to the hydroperoxide, then para-anisidine value is a good parameter in determining the aldehyde degree of the oil oxidation during frying. Para-anisidine value is stated as 100 times of the optical density measured in 350 nm within cell of 1 cm of the solution containing 1 gr of oil and 100 mL of the combined solvent and reagent.^{4,7,23}. The higher temperature and length of palm oil heating thus p-AV more increases due to the existence of aldehyde compound of the auto-oxidation result of the cooking oil which does not easily evaporate²³.

Another oil quality indicator is total oxidation value of the oil. Total oxidation (TOTOX) value is calculated under peroxide and para-anisidine values. TOTOX value formula = $2 \cdot PV + P-AV$. Based on the formula, it shows that TOTOX value is the totaling of peroxide oxidation result and the hydroperoxide oxidation result. Non-volatile aldehyde compound which is resulted is the measure of oxidation occurrence in cooking oil. Oil which is more stable against oxidative rancidity which has lower TOTOX value^{4,7}.

Evaluation of oil damage can be measured based on total polar compounds (TPC) in the oil. TPC is stated in the TPC percentage which is the evaluation of the oil damage during the frying²¹. The oil damage caused by high frying temperature will form peroxide and hydroperoxide which is later decomposed will form aldehyde compounds, short chain acids, and ketone and non-volatile compounds. TPC value can be used as the basis that the oil is no longer good to be re-used and must be disposed (Debnath et al., 2012; Nayak et al., 2016). Percentage of palm oil TPC linearly increases with the frying duration. The higher temperature and the longer frying duration then the TPC percentage is getting higher^{21,23,24}. Description of hydrolysis and oxidation process and reaction main product of frying process and its evaluation parameter is displayed in form of the chart adopted from Ganesan (2018) and Nayak (2016) in Figure 1.



Note: Chart of main product and evaluation parameter of oil quality ^{3,4}, PV: Peroxide value, IV: iodine value, TOTOX: total oxidation, P-AV: para-anisidine value, TPC: total polar compound, FFA-V: free fatty acids value.

Figure 1. Evaluation Parameter of oil Quality Resulted from Hydrolysis and Oxidation of Frying Process

Table 1. Different chemical analysis on palm oil during frying/heating oil

No.	Temperature (°C)	Length of frying/heating g	Repeated frying/heating g	Fried material	Analysis	Range	References
1.	150, 165, 180°C	24, 40 h	n.a	Potato	FFA, TPC,	1.5%–1.16% 18%–23%	⁵
2.	150, 200, 250°C	2, 4, 6, 8 h	Fried 10 min, interval 6 min, at 8 h/day	Chicken fillets	PV, TFA (C _{18:2}), FFA (C _{16:1})	0.88–1.8 (mg/g) 1.07–1.22 (mg/g)	¹⁰
3.	180°C	0,25, 10, 20, 30, 40, 50 h	n. a	Potato	FFA, TPCs,	13.7–4.97% 6.06–31.65%	⁶
4.	160-180°C	n.a	1,3,5,7,9	Potato	PV,	1.96–13.44 meqO ₂ /kg	²⁵
5.	180°C	8, 24, 40 h	Fried 4 min, interval 6 min at 8 h/day	Potato	Polymer, FFA, TPC	0.4–1.0% 0.065–0.42% 7.0–15.6%	¹⁵
6.	180°C	8, 16 h	Fried 6 min, interval 10 min at 16 h for 2 days	Potato	FFA, PV, IV	0.069–0.343% 1.6–10 meq/kg 87–77 IV	²⁶
7.	180°C	5 h, 14 h, 24 h	Fried 2,5 min, 5 days	Potato	p-AV, PV, FFA, TPCs,	Max PV 11.6 meq/kg 0.1–0.51% 3.83–17.66%	¹⁴
8.	170°C	10 h	Fried 8 min,	Potato	Polymer,	0.79–3.98%	¹⁶

			interval 30 min at 10 h		IV, PV, FFA, TPC	56.95–55.3% 0.69–0.83% 0.77–1.09% 5.3–11.4%	
9.	180°C	8, 16, 24, 32, 40, 48 h	Fried 25 min, interval 10 min at 16 h for 2 days	Potato	PV, TFA, FFA, TPC,	4.99–4.82 meq/kg g 0.06–0.43% 0.16–1.83% 11.70–28.5%	¹
10.	180°C	1/6 h	Fried 10 min, 5x	Banana, chicken	TFA	0.085–0.12%	²⁷
11.	n.a	n.a	n.a	42 sample at <i>fast food</i> restaurant	Acids value TPC PV,	0.06–1.43 mg KOH/g 5.0–24.2 % 1.5–41.5 meq/kg	¹³
12.	160°C, 190°C	n.a	Fried 4 min, 3 x frying	Potato	PV, IV, SV, TFA, FFA, TPC,	2.5–4.5%	⁹
13.	160-180°C	3,5 h; 7 h, 10,5 h; 14 h, 17,5 h, 21 h	Fried 6 min, interval 10 min at 3,5 h/day, for 6 days, 10 frying sesi/day	Bean cake	MUFA PUFA SFA	31.26–34.56% 9.49–10.18% 59.24–55.21%	²
14.	180°C	3,5 h; 7 h, 10,5 h; 14 h, 17,5 h,	Fried 2,5 min, interval 17,5 min at 3,5 h/day, 5 days, 10 frying sesi/day, 50 frying sesi 5 days	Potato	IV, Fatty acids composition (total unsaturated)	57.27–52.81% 58.6–52.6%	²²

Note: FFA: free fatty acids, TPC: Total polar compound, PV: peroxide value, IV: Iodine value, p-AV: para-anisidine value, SV: saponifikasi value, TFA: transfatty acids, Fatty acids composition, na: non-applicable.

Some researches which have been conducted against palm oil, against temperature variation, various length of frying and repetition under the parameter of oil chemical damage showed in table 1. The longer oil is used to fry then the oil is increasingly damaged. The same temperature (180°C) with length of frying until 50 hours caused higher oil damage, total value of polar compound (TPC) 31.65% > 25% of the oil has been damaged and must be replaced. The longer oil is used, the lower free fatty acid (FFA) value, which means free fatty acids have been degraded in form of polar compound or other polymer compound. It is pursuant to the iodine value, the higher temperature and the longer frying then the iodine value is increasingly lower where the mono-unsaturated fatty acid with double bound reduced due to its disconnection/detachment from the double bound. Trans-fatty acid is formed by the longer frying.

3. Composition Change of Palm Oil Fatty Acid During Frying

3.1 Compositions of PUFA, MUFA, SFA

Oil change occurs during the frying in saturated fatty acid and mono-unsaturated fatty acid which is affected by temperature and frying duration and repeated oil use. The oil heating with temperatures of 150°C, 200°C, 250°C with different lengths results in different concentrations of saturated fatty acid and mono-unsaturated fatty acids. Concentrations of MUFA and PUFA fatty acids at the temperature heating of 150°C, 200°C, heating duration of 2, 4, 6 hours underwent the increase, however, in the heating of 8 hours, the concentration of MUFA reduces. Contradicted to the heating of 250°C, the concentrations of MUFA and PUFA underwent the increase until duration of 8 hours¹⁰.

The study of Li et al(2017) found that concentrations of SFA and UFA in the oil used to fry potato at the temperature of 180°C, the longer oil used until 50 hours of frying, the higher concentrations of SFA and UFA. Frying which uses relatively low temperatures (150°C-165°C) until the 4th frying repetition does not increase concentrations of SFA and PUFA fatty acids. It is pursuant to the study of Malkan (2015) which stated that by frying tofu, there is no significant increase of saturated fatty acids and mono-unsaturated fatty acids concentrations until the 4th frying.

The higher frying temperature, the longer frying duration, then the ratios of PUFA and SFA increasingly decreases. PUFA and SFA fatty acids used to calculate ratio is linoleic acid (C_{18:2}) and palmitate acid (C_{16:0}). The lower ratio of mono-unsaturated fatty acids and saturated acids affects the quality and the storage age of the oil^{1,5,6,10}. Ratio of linoleic/palmitate (C_{18:2}/C_{16:0}) of fresh palm oil is 0.24, after being heated at the temperature of 180°C for 40 hours, then the ratio of C_{18:2}/C_{16:0} decreases into 0.17⁵.

3.2 Composition of Fatty Acid and Trans-Fatty Acid

In the oil heating at the temperatures of 150°C, 200°C, the concentration of free fatty acids is formed unstable at the different length of heating (2,4,6,8 hours). However, at the temperature of 250°C, there occurs the increase of fatty acids concentration in the increased length of heating. Fatty acid whose concentration increases is palmitic (C_{16:1c}) 1.19mg/g which in 2 hours increases 1.22mg/g in the 8 hours of frying, which means there occurs the concentration increase of 2.521% in line with the longer frying duration. Oleic fatty acids also have the concentration increase in line with the increased length of frying 331.55mg/g in 2 hours increases into 353.65mg/g in the 8 hour of frying, there is an oleic concentration increase of 6.67%. However, contradicted to the concentration of linoleic (C_{18:2cc}), the longer frying then the concentration decreases from 70.75 mg/g in the 2 hours of frying which reduces into 57.69mg/g in the 8 hours of frying; there is the concentration reduce of 22.6%¹⁰. Likewise the study of Aniołowska & Kita(2016), the increase of temperature (180°C) and frying duration (40 hours) will make the higher concentrations of palmitate acid and stearic acid, meanwhile concentrations of oleic, linoleic, and linolenic acids will be more reduced.

Trans-linoleic fatty acid (C_{18:2t}) has been formed in the heating of 150°C and 200°C, however, concentration varies in the different length of frying (2, 4, 6, 8 hours). Frying temperature of 250°C, concentration of trans-linoleic acid (C_{18:2t}) has a positive correlation with the length of heating. For trans-linoleic acid (C_{18:2tt}), there is a concentration increase from 2 hours until 8 hours of frying of 51.3%-63%. Trans-elaidic fatty acid (C_{18:1t}) has a positive correlation against the length of frying, until the heating of 4 hours is undetected, however, in the heating of 6 hours, the concentration of elaidic sharply increases until 2mg/g and increases in the 8 hours of heating. Linolenat fatty acid (C_{18:3ctt/cct}), linolenat C_{18:3tcc}) are undetected in the heating of 150°C and 200°C, but they are detected in the heating of 250°C with the concentration range

of 0.16–0.31mg/g^{6,10}. It is different to the study of Romano (2012) that trans-elaidic fatty (C_{18:1t}) in the heating of 180°C for 8 hours has been detected and will keep increase until 48 hours of heating namely 0.13%-0.40% with the increase of 207.7%.

The study of Li et al(2017) states that the concentration of trans-linoleic fatty has a negative correlation with the length of frying at the temperature of 180°C in which the longer frying then the concentration of trans-fatty will be more reduced. Likewise the study of Romano et al (2012), the concentration of trans-linoleic fats (C_{18:2t}) varies along with the longer frying, in the 8 hours of frying 0.02% increases into 0.03% in 24 hours and decreases in 32 hours of 0.02% and increases 0.05% in the frying of 40 hours and more decreases in the frying of 48 hours i.e. 0.03%.

4. Frying Effect against Contaminants in Palm Oil: Trans-Fatty Acid and Glycidyl ester

4.1 Frying Effect against Trans-Fatty Acid

Frying at temperatures of 150°C and 200°C for 2 hours in the palm oil has detected trans-linoleic fats (C_{18:2,19/112}). At the temperature of 250°C, besides trans-linoleic fats (C_{18:2,19/112}) it is also found trans-linolenic fats (C_{18:3,cct/ctt}). The longer frying, the higher and more stable concentration of trans-fats during the repeated frying process, especially trans-linolenic (C_{18:3,ctt/cct}). Linear relationship between the amount of total trans-linoleat acid and frying duration is also observed. Meanwhile trans-fats C_{18:1} is detected after 4 hours of frying at 250°C, trans-fats C_{18:3} is detected after 2 hours of frying at 250°C¹⁰. In frying carbohydrate-based food material, the concentration of trans-linoleic in potato frying oil is detected in the beginning of the frying, however, the longer frying until 50 hours, the concentration of linoleic is increasingly reduced⁶. Malkan et al (2015), conducted the tofu frying at the temperature of 150°C–165°C and there is no significant increase of trans-elaidic concentration until the 4th frying.

In another study using carbohydrate-based material (cassava) and protein-based material (cow meat), trans-elaidic fats is found in cassava frying oil. In each cassava frying repetition, it results in elaidic; in the 2nd frying repetition with frying duration of 30 minutes (0.37%); in the frying duration of 15 minutes, trans-elaidic fats is found in the 3rd repetition (0.54%), and the more frequent repetition, the more increased concentration of elaidic fats concentration (0.73%) in the 4th frying repetition for 30 minutes. In the 1st frying when the concentration of elaidic fats is found in cow meat frying oil, its concentration is increasingly higher by the more frequent the oil is used until the 4th repetition (1.2%) at the same temperature (200°C). The frying process with deep fat frying against oleat and elaidic concentrations has a reverse relationship in the repeated frying²⁰.

Table 2. Concentrations of trans-fatty acids in palm oil after food frying, as affected by different heating temperatures and duration

Temperature (°C)	Duration (h)	Trans fatty acid	Concentration (mg/g)	Total concentration (mg/g)	Reference
150-165	2	9t C _{18:1}	0.8*	0.8	²⁸
150	8	9c12t C _{18:2}	0.9***	1.7	¹⁰
		9t12c C _{18:2}	0.8***		
160	0.25	9t C _{18:1}	0.4**	3.8	⁹
		Total trans C _{18:2}	3.0**		
		Total trans C _{18:3}	0.4**		
170	10	Trans fat	2.0**	2.0	¹⁶

180	16	9t C _{18:1}	2,2**	5.0	11
		Total trans C _{18:2}	2,8**		
180	48	9t C _{18:1}	4,0**	4.3	1
		6t9c C _{18:2}	0,3**		
180	50	9t C _{18:1}	3,7**	4.2	6
		Total trans C _{18:2}	0,5**		
190	0,25	9t C _{18:1}	0,30**	3.8	9
		Total trans C _{18:2}	3,10**		
		Total trans C _{18:3}	0,40**		
200	8	9c12t C _{18:2}	0,9***	1.7	10
		9t12c C _{18:2}	0,8***		
200	0.033	9t C _{18:1}	0.13*****	0.13	20
	0.5	9t C _{18:1}	0.37*****	0.37	
250	8	9c12t C _{18:2}	1,8***	4.1	10
		9t12c C _{18:2}	1,8***		
		Total 9c12t15t	0,3***		
		C _{18:3} 9c12c15t			
		C _{18:3}	0,3***		
		9t12c15c C _{18:3}			

Note: *oil used in frying tofu, ** oil used in frying potato, *** oil used in frying chicken, **** oil used in frying cassava, ***** oil used in frying cow meat.

Heating of palm oil frying in different temperatures and various duration results in different concentration of trans-fats as well. In table 2, it is displayed that trans-fatty acids which are formed from the frying process are trans-elaidic (C_{18:1,9t}), trans-linoleic (C_{18:2,9c12t/9t12c}), and total trans-linolenic (C_{18:3,9c12t15t/9c12c15t/9t12c15c}). Trans-elaidic fatty acid (C_{18:1,9t}), trans-linoleic fatty acid (C_{18:2,9c12t/9t12c}), are already formed at the temperature of 150-200°C of the frying. Trans-linolenic fatty acid (C_{18:3,9c12t15t/9c12c15t/9t12c15c}) is detected in the frying temperature of 250°C, below 250°C is undetected.

Based on table 2, there is an increase of trans-fatty acid concentration in the frying process. Trans-elaidic fatty acid (C_{18:1,9t}) at the temperature of 150°C of the frying has been detected after the frying of 2 hours. In temperature of 160°C with shorter duration of 0.25 hour or 15 minutes, the concentration of trans-elaidic fatty acid (C_{18:1,9t}) is lower (0.4mg/g). The higher frying temperature and duration, the higher concentration of trans-elaidic (C_{18:1,9t}) is formed. At the temperature of 180°C and 48 hours of frying, the concentration of trans-elaidic (C_{18:1,9t}) achieves 4.0mg/g. Duration increase is three times longer (48 or 50 hours compared to 16 hours) then elaidic concentration increases into double. Trans-linoleic fatty acid (C_{18:2,9c12t/9t12c}) at the temperature of 150°C has been detected namely 1.7mg/g for the frying of 8 hours. When using temperature of 160°C with duration of 0.25 hour (15 minutes), the concentration which is formed is higher (3.0mg/g). However, contradicted to another study which uses frying temperature of 180°C for 16, 48, 50 hours, the formed concentration is lower namely 2.8mg/g, 0.3mg/g, and 0.5mg/g. Trans-linolenic fatty acid with 3 double bonds (C_{18:3,9c12t15t/C_{18:3,9c12c15t/C_{18:3,9t12c15c}}) is detected in the frying with temperature of 250°C. In average, total concentration in the frying duration of 8 hours is 0.3mg/g. The higher frying temperature and the longer frying duration, the formed trans-fatty acid will be higher and type of trans-fatty acid is increasingly varied.}

4.2 Frying Effect against Glycidyl esters

Glycidyl esters in palm oil is formed during the processing process of palm fruit into palm oil, in the purification process particularly during the deodorization in temperature of 240°C-260°C. Other than caused by high heating from deodorization process in palm oil, length of heating will increase the concentration of glycidyl esters, the longer heating, the higher concentration of glycidyl esters will be formed (Cheng, Liu,

Wang, & Liu, 2017; Craft, Nagy, Seefelder, Dubois, & Destailats, 2012; Destailats, Craft, Dubois, & Nagy, 2012). At temperature of 250°C, formation of glycidyl esters more increases along the time and being stable in the system due to glycidyl esters do not easily evaporate. The increase of glycidyl ester precursor will increase the concentration of glycidyl ester. Glycidyl esters are compounds resulted from the hydrolysis of triacylglyceride (TG)³³. Glycidyl esters are contaminant compounds available in palm oil which is toxic in nature which causes cancer³¹. World Health Organization (WHO) 2010 categorizes glycidyl esters as compounds of group 2A namely probably carcinogenic. Glycidyl esters are genotoxic carcinogenic compounds, thus they have no value of tolerable daily intake (TDI) (JECFA, 2018).

The study conducted by Weißhaar & Perz, (2010) stated that in average the concentration of glycidyl esters in pure palm oil is 2,38mg/kg with the range of 0,32-6,3mg/kg and this value depends on the condition of deodorization process as conducted, such as temperature and length of heating. Study against frying effect with glycidyl esters concentration has been researched. Fresh potato chips frying uses palm oil in various temperatures i.e. 150°C, 165°C and 180°C with frying duration of 30 minutes and total length of frying of 8 hours each day. Concentration of glycidyl ester compounds has been observed for 5 days. Concentration of glycidyl esters of the palm oil which is still fresh becomes reduced since it is used for frying. Such compound concentration reduction has appeared in the frying temperature of 150°C. During the frying process, the concentration of glycidyl ester reduces, it occurs in all compounds of glycidyl esters i.e. C_{16:0}-GE, C_{18:0}-GE, C_{18:1}-GE, C_{18:2}-GE. However, the concentration of C_{18:3}-GE below the value of 0.095mg/kg or undetected. Frying temperature and length of frying are closely related to the concentration of glycidyl esters in palm oil. If the frying uses different temperature, the concentration of glycidyl esters of the palm oil is also different, likewise with the length of frying. The higher frying temperature, the reduction of glycidyl esters concentration is higher. The use of 180°C will provide lower concentration of glycidyl esters compared to the temperature of 150°C. The longer frying at the same temperature, the concentration of glycidyl esters will also increasingly reduce. The reduction of glycidyl esters concentration in fresh palm oil until 87% occurs in the frying with temperature of 180°C and total frying duration of 40 hours⁵. Description on the reduction of glycidyl esters during this frying is still unable to be well-explained.

5. Conclusion and Recommendation

Frying process which uses high temperature and long frying duration is the cause of the oil damage. The oil damage is indicated with the formation of aldehyde compounds, short chain fatty acids, and other polar compounds. Oil which is damaged is indicated with high peroxide value, decreased iodine value, increased para-anisidine value, free acid value and percentage of total polar compound until 25 %. Formation of toxic contaminant namely trans-fatty acid and glycidyl esters due to high temperature use for frying is also observed in several studies. In this review result, the frying uses temperature of 150°C-165°C with twice (2) repetition and length of frying is not more than 4 hours is the recommendation for the use of palm oil within the process of deep fat frying.

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