Relationship of Frying Temperature with Frying Life of Selected Oil Types

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RESEARCH ARTICLE

Abstract

Background: Cooking oils used for long periods of frying are subject to oil deterioration. Total polar compounds (TPC) is the general parameter used to quantify oil deterioration wherein the maximum allowable TPC of cooking oil is 25%. The time it takes to reach 25% TPC was defined as the frying life of oil.
Objectives: This study was undertaken to determine the effect of oil type and frying temperature on frying life.
Methodology: The frying lives of coconut, canola, and palm oil as well as the oils heated at 150ºC, 170ºC, and 190ºC were determined. Spectrophotometric analysis was performed and the TPC values were calculated from absorbance using the equation: y = -2.7865x2 + 23.782x + 1.0309.
Results and Discussions: The mean frying lives were 20.24h, 10.80h, and 13.49h for coconut, canola, and palm oil, respectively. Regardless of oil types, the mean frying lives were 16.23h, 11.93h, and 13.82h at the following frying temperatures namely; 150ºC, 170ºC, and 190ºC , respectively. Two-way ANOVA showed a significant difference in the frying lives of the three oil types and those of the three frying temperatures.
Conclusion: Coconut oil had a longer mean frying life than both palm and canola oil. In terms of frying temperature, the longest mean frying life was observed in the oils heated at 150ºC, followed by the oils heated at 190ºC. There was a significant interaction between oil type and frying temperature observed in the study.

Keywords: *frying life, oil type, coconut oil, canola oil, palm oil, frying temperature*

Introduction

An increase in the availability and consumption of energy-dense high-fat diets is notable in the developing world [1]. Deep frying, which involves prolonged heating of cooking oil, is a popular practice utilized in the majority of food sectors, such as street food joints, fast-food establishments, restaurants, as well as in households. Consumption of foods cooked using oils heated for an extended amount of time is a risk factor for the development of cardiovascular diseases. Cardiovascular diseases caused 33% of the total deaths in all ages in both sexes, according to the 2010 Philippine Health Statistics [2]. Worldwide, they were responsible for the largest proportion of NCD deaths under the age of 70, as stated by the 2014 Global Status Report on Non-communicable Diseases [3].

Prolonged heating of cooking oil prompts chemical reactions which hydrolyze and oxidize the oil, that may result in the formation of compounds associated with cardiovascular diseases. Among these are free fatty acids [4,5] which may cause hypertension and atherogenic dyslipidemia [6]. Oxidative stress may also result in the production of fixed oxidation compounds and free radicals, which are highly reactive and carcinogenic [4]. Reactive oxygen species may also be formed as a result of the decrease in antioxidants brought about by thermal abuse [7,8].

Existing regulations aimed at promoting food safety in the food industry, such as the RA 10611 [9] or the Food Safety Act of 2013 [10], focus on the sanitation and prevention of microbiological hazards in foods. Hazards brought about by exploitative oil heating are classified as chemical hazards, and these are not prioritized.

Despite numerous studies proving the health hazards associated with eating foods cooked in these oils, there continues to be a lack of a specific policy prohibiting food handlers from excessively heating oils [11]. There is no available data [10] regarding the maximum allowable time for

cooking oil to be heated without becoming a health risk, which is needed by policymakers as basis for the regulation of oil use in different food establishments. This study aimed to determine the maximum allowable heating time for selected oil types based on the chemical quality of the oil, measured by the amount of Total Polar Compounds (TPC) present in the oil. TPC encompasses almost all the degraded products [12] formed during frying, which are mainly responsible for the cardiovascular health risks associated with consumption of food cooked using excessively reheated oil [13]. These include the diglycerides, monoglycerides, free fatty acids, oxidized triglycerides, secondary oxidation compounds, triglyceride dimers and polymers, cyclic monomers, and oxidized dimers and polymers, among others [14].

Methodology

O*bjectives.* The primary objective of the study was to determine the relationship of frying temperature with the frying life of selected oil types. Frying life herein refers to the amount of heating time, in hours, of the frying oil required for the amount of TPC to reach at least 25 percent. The limit set was 25% TPC because this was the recommended maximum limit of TPC as proclaimed during the 7th International Symposium on Deep-Fat Frying in 2013 held in San Francisco, California [15]. The study determined the frying life for each oil type at each of three frying temperatures. The frying lives of the different oil types at the different frying temperatures were compared, and the interaction effect of oil type and frying temperature on frying life was also determined.

Materials. The study materials in this study were comprised of the cooking oils, specifically, coconut oil, canola oil, and palm oil. These were selected as these were the most commonly used in the Philippines according to consumer sales from 2010 to 2015 [9].

Study Design. This study utilized an experimental factorial design. The minimum sample size required for this study was 18, as computed using Factorial Analysis of Variance under the PASS Software. Therefore, a minimum of two samples was needed for each treatment combination. Two oil brands per oil type were used for this. There was no need to have replicates within each brand, however, the researchers opted to have duplicates.

Procedure

Heating of Oil Samples. The oils were heated using an induction cooker. Thirty milliliters (30 ml) of each oil sample were placed in metal containers of equal size and volume, lined with aluminum foil. Heating time was assigned to each sample, at time points spaced five hours apart, starting from zero hours. Each of the two oil brands for each oil type was subjected to three frying temperatures: 150ºC, 170ºC, and 190ºC. These were chosen since the usual frying temperature of oils range from 150ºC to 190ºC, with the optimum temperature being 160ºC to 180ºC [12]. Temperature intervals were set to 20ºC apart since other studies which had narrower temperature interval (i.e., 10ºC) had negligible variations among adjacent values [16]. Frying temperature was measured using deep fry thermometers, and maintained with fluctuations of at most +5˚C. For the entire heating process, heating was performed inside a fume hood to minimize interferences from the external environment (i.e., moisture). The oils were not stirred or agitated in any way during heating.

Storage of oil samples. Upon completing their designated heating time or at the end of the work day, oil samples were removed from the cookers, cooled for five minutes, and sealed with aluminum foil. The metal containers used for heating were also the ones used to store [17] the samples in a refrigerator maintained at 6ºC [18]. Oil samples which have not completed their designated heating time were stored until the next working day [19], wherein they were heated again. Heating time, therefore, was cumulative.

Spectrophotometric analysis of oil samples. Oil samples that have completed their heating time were obtained from storage then heated to 50ºC [20] while being mixed with a stirring rod. One and a half milliliters (1.5 ml) of each sample were obtained and transferred to each of four clean cuvettes. The absorbances of the oil samples were then measured using a UV-Vis spectrophotometer at 490 nm. The UV-Vis spectrophotometer was chosen as it has met the recommended characteristics of rapid test methods for oil quality assessment reported during the 7th International Symposium on Deep-Fat Frying in 2013 held in Hagen/Westphalia, Germany [13]. TPC was calculated from absorbance using the equation by Xin-Qing Xu:

$$y = -2.7865x2 + 23.782x + 1.0309$$

(where x = absorbance and y = TPC).

The unheated oil (0h heating time) served as the blank reading. For each brand of each oil type, the heating time of the first oil sample whose computed TPC value was at least 25% was designated as the frying life of that oil sample at the particular temperature in which it was heated. The equation used was based on frying oils used for frying potato chips as it is the only available estimates during the time of study.

Data processing and analysis. Two-way ANOVA was used to determine whether the three oil types had significantly different frying life and whether the three frying temperatures were significantly different from each other in terms of frying life. Pairwise comparison tests were used to determine which among the three oil types and three frying temperatures were significantly different from each other when compared in pairs. Linear correlations were also done per frying temperature in the three oil types with duration of heating in the x-axis and the TPC on the y-axis.

Results

The sampling population was comprised of the three oil types used: canola, coconut, and palm heated at three frying temperatures: 150ºC, 170ºC, and 190ºC. Two brands per oil type were used to meet the minimum sample size requirement of 18. A total of 587 replicates were measured for the 18 oil samples used in this study.

Frying Life of Canola, Coconut, and Palm Oils

The mean frying lives of canola oil, coconut oil, and palm oil were 10.80 hours, 20.24 hours, and 13.49 hours, respectively. Two-way ANOVA showed that there was a significant difference in the mean frying lives of canola, coconut, and palm oils, as indicated by a p-value (0.00) which was less than the alpha (0.05).

Post hoc analysis using pairwise comparison test showed that coconut oil and canola oil had significantly different frying lives, as did coconut oil and palm oil. This was shown by the ranges of the unadjusted 95% confidence interval for both tests: coconut oil and canola oil (7.15, 11.14) and coconut oil and palm oil (-9.44, -5.40), which did not include the null value of 0. However, the 95% confidence interval range for palm oil and canola oil (-0.07, 3.52) included the null value indicating that there was no significant difference between the frying lives of palm oil and canola oil.

Table 1. *Fatty acid composition of palm oil [25]*

Type of Fatty Acid	Concentration
Saturated Palmitic acid 16:0 Stearic acid 18:0 **Unsaturated** Oleic acid 18:1 n-9 Linoleic acid 18:2 n-6	48% 44% 4% 50% 40% 10%
Other	2%

Figure 1 shows the raw experimental results, comprised of TPC values at successive hours of heating until TPC either reached or exceeded 25%. The results of the study were congruent with the findings of Houhoula, Oreopoulou, and Tzia [21], as well as those of Chen *et al*. [22], which showed that percent TPC increased linearly with increase in frying time.

Effects of Oil Type

Fatty Acid Composition

In general, oils containing fatty acids with a higher degree of saturation are more stable in that they are less vulnerable to oxidation and free radical formation [23,24]. The difference found in the frying lives of the three oils used could then be attributed to the differences in their fatty acid composition.

Saturated fatty acids comprise a majority of both palm oil and coconut oil's fatty acid composition, as shown in Tables 1 and 2. However, whereas the saturated fatty acid content of palm oil only amounts to 50%, that of coconut oil amounts to more than 90%. Moreover, lauric acid comprises

Table 2. *Fatty acid composition of coconut oil [25]*

Type of Fatty Acid	Concentration
Saturated Lauric acid 12:0 Myristic acid 14:0 Palmitic acid 16:0 Caprylic acid 8:0 Capric acid 10:0 Stearic acid 18:0 **Unsaturated** Oleic acid 18:1 n-9 Linoleic acid 18:2 n-6	90% 48% 16% 9% 8% 7% 2% 9% 7% 2%
Other	1%

Table 3. *Fatty acid composition of canola oil [29]*

Type of Fatty Acid	Concentration
Saturated Palmitic acid 16:0 Stearic acid 18:0 **Unsaturated** Oleic acid 18:1 n-9 Linoleic acid 18:2 n-6 Linolenic acid 18:3 n-3	6% 4% 2% 92% 56% 26% 10%
Other	2%

more than 50% of coconut oil's saturated fatty acid content, whereas it does not exist in more than 1% of other oils, including palm oil. Lauric acid is a component known to greatly increase oil's oxidative stability [10,23]. This, in addition to coconut oil's already high saturated fatty acid content compared to palm oil's, explains the significantly longer frying life of coconut oil than palm oil.

Coconut oil was also found to have a significantly longer frying life than canola oil. Canola oil, as shown in Table 3, is comprised of 60-85% oleic acid, an unsaturated fatty acid [25,26]. As mentioned previously, a higher degree of unsaturation results in a higher susceptibility to oxidative degradation [27,28].

There was no significant difference found between the frying lives of palm oil and canola oil despite the differences in their saturated fatty acid composition. This could be explained by the high amount of long-chain fatty acids (C16 and C18 length) present in palm oil, which are more susceptible to oxidative processes (i.e., beta oxidation) whose purpose is to shorten these fatty acids. Furthermore, oleic acid accounts for 40% out of its 50% unsaturated fatty acid content, and is thus a major component of palm oil, as it is in canola oil [27]. This may have resulted in the similarity of frying life between the two.

Refining Process

All oils used in the study were refined variants, but while the refining process undergone by coconut oil is a physical one, those undergone by canola and palm were chemical processes. In coconut oil, upon refinement, impurities are minimized by removing moisture, solid particles, metal ions, volatiles, and oxidation products. Some free fatty acid are also removed and all of these add to the already high stability of coconut oil against oxidative stress [23].

The chemical processes palm and canola oil undergo generally involve a degumming pretreatment, a bleaching step, and a high-temperature-low-pressure deodorization step. These processes remove a considerable amount of saturated fatty acids and antioxidants, resulting in an oil more suited to market demands (i.e., color, odor), but also more vulnerable to oxidative degradation. This may have contributed to the significantly longer frying life of coconut oil compared to that of palm oil and canola oil, as well as the lack of a significant difference between the frying lives of palm oil and canola oil [23].

Frying Life at 150ºC, 170ºC, 190ºC

The mean frying lives of the oils at 150ºC, 170ºC, and 190ºC were 16.23 hours, 11.93 hours, and 13.83 hours, respectively. There was a significant difference between the frying lives of the oils heated at the three temperatures since a p-value (0.0003) less than alpha (0.05) was obtained after analysis. The statistical difference seen among the three showed that frying temperature indeed had an effect on frying life. This was consistent with the findings in a study done by Kupongsak and Kansuwan [29], which reported that frying temperature had a significant effect on the free fatty acid level of cooking oil.

Pairwise comparison of the different frying temperatures showed that the frying life for 150ºC and 190ºC (16.23h, 13.83h) were significantly different. Similarly, the difference between the frying lives of oils heated at 150ºC and 170ºC (16.23h, 11.93h) were also significant. However, there was no significant difference between the frying lives of 170ºC and 190ºC (11.93h, 13.83h) since the 95% confidence interval range for their difference included the null value of 0.

A significantly longer frying life was observed in oils heated at 150ºC compared to those heated at 170ºC and those heated at 190ºC. This showed congruence with findings in previous studies, which state that an increase in temperature would yield an increased rate of TPC formation [13]. It follows, then, that at lower temperatures, the rate of TPC formation is slower, and therefore, the frying life would be longer.

The mean frying life of oils heated at 170ºC was not significantly different from the mean frying life of oils heated at 190ºC. This finding was in agreement with a study done by Houhoula *et al*. [16] where oils kept at high temperatures (175ºC and 195ºC) had an even more pronounced triglyceride polymerization compared to those heated at lower temperatures. Thermo-oxidative reactions were predominant in frying and were more distinct at high temperatures. Likewise, in a study of critical points in deep-fat frying, Soriano, Moltó, and Mañes [12] reported that higher temperatures, especially over 200°C, accelerated oxidative and thermal alterations and increased the rate of formation of decomposition products. It is possible, then, that when frying at these high temperatures, the rate of TPC formation reaches its maximum, thus explaining why the time it took to achieve 25% TPC was not significantly different for both temperatures. However, there are no supporting studies for this account as of the moment.

This disagreement between the study results and data from literature may also be due to instrumentation errors over the course of data collection. However, pre-testing was performed to minimize such errors, therefore, further studies need to be conducted in order to explain the findings.

Interaction between Oil Type and Frying Temperature

Two-way ANOVA showed that there was a significant interaction between the effects of oil type and frying temperature on frying life, as indicated by the p-value (0.0001), which was less than the alpha, 0.05. Thus, the main effects of oil type and frying life could not be interpreted without considering the interaction effect. That is, the relationship of frying temperature and frying life is dependent on oil type. Similarly, the relationship of oil type and frying life is dependent on frying temperature. A visualization of the interaction effect is presented in Figure 2.

The relationship of frying temperature with frying life was observed in previous studies. According to a study of deep-fat frying of French fries by Kupongsak and Kansuwan [29], it was found that as the temperature and time increased in a frying condition, the polar compounds also increased. There was a positive linear relationship between frying temperature and TPC production until a certain degree of heat is achieved wherein the rate of TPC production starts to accelerate [16]. The relationship of temperature and TPC production can be paralleled to the relationship of temperature with frying life.

In the same manner, the relationship of oil type with frying life was ascertained in literature. A study done by Takeoka *et al*. [30] found that heating produced more polar compounds in oils with higher levels of UFA compared to the more saturated oils. Thus, canola oil, being rich in unsaturated fats, yielded a shorter frying life. Likewise, palm oil having approximately 50% saturated fatty acid (SFA) composition produced a relatively longer frying life and coconut oil having a 90% SFA composition produced the longest frying life [31,32].

There were, however, no other studies found that showed the effect of oil type on the relationship between frying temperature and frying life. No studies on the effect of frying temperature on the relationship of oil type and frying life were available either.

Limitations of the Study

Due to logical constraints in the laboratory, other factors that could have a possible effect on the rate of TPC formation were not controlled. Among these were the ambient temperature, humidity, and altitude of the laboratory where the procedure was performed. Intermittent heating was also inevitably included in the setup, although this was minimized through the use of different oils for each designated heating time. Furthermore, deterioration of the pans over time such as color darkening and rubbing at the base and sides of the pan as a result of repeated overheating and frequent cleaning were not prevented as these were functions of the quality of the materials used.

Heating time was set at 5-hour intervals to make the entire process more feasible. This meant that the exact point at which 25% TPC was reached was not directly observed. The equation used for calculating frying life was based on frying oils used for frying potato chips, thus, the frying life could have been under or estimated due to the use of frying oils only. However, this was done because of logistical constraints since heating the oils with food sample might complicate the calculation as we also have to account for the effect of different food types.

The study was restricted to UV-Vis spectrophotometric analysis. Although the standard AOCS method for determining TPC values in oil is Silica Gel Column Chromatography, along with other methods such as High-Performance Liquid Chromatography and Gas Chromatography, these sophisticated assays were not feasible for use in this study as they required skilled personnel, large consumption of solvents, high costs, and long analysis time. Furthermore, in the data presentation, absorbance was not presented as time points with standard deviation as error bars, as the study utilized an equation to calculate frying life which included the absorbance, hence it may not be practical to present it as it is.

Conclusion

As of date, there continues to be limited knowledge on the proper usage and reusing of cooking oils. This study focused on determining the maximum amount of time of heating of different oil types across varying temperatures until it reached unsafe levels.

The results of the study showed that coconut oil had a longer mean frying life than both palm and canola oil. Palm oil, on the other hand, has a longer frying life than canola oil. In terms of temperature, the longest mean frying life was observed in the oils heated at 150ºC, followed by the oils heated at 190ºC. The oils heated at 170ºC had the shortest mean frying life.

Statistical analyses indicate that the three oil types had significantly different frying lives per frying temperature. It was also concluded that oils heated at higher temperatures had a shorter frying life than those heated at lower temperatures. Furthermore, the three frying temperatures had significantly different effects on frying life per oil type.

There was a significant interaction between oil type and frying temperature. This means that the relationship between frying temperature and frying life depends on oil type and the relationship of oil type and frying life depends on frying temperature. Because the interaction effect between oil type and frying temperature is statistically significant, the main effects of these two variables cannot be interpreted without considering the interaction effect.

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