Hindawi
Journal of Food Biochemistry
Volume 2023, Article ID 6598528, 11 pages
https://doi.org/10.1155/2023/6598528

Research Article

Oxidative Changes in Ten Vegetable Oils Caused by the Deep-Frying Process of Potato

Birsen Yılmaz,[1] **Teslime Özge Şahin**,[2] **and Duygu Ağagündüz**[2]

[1]*Department of Biological Sciences, Tata Institute of Fundamental Research, Hyderabad, India*
[2]*Gazi University, Faculty of Health Sciences, Department of Nutrition and Dietetics, Ankara, Turkey*

Correspondence should be addressed to Duygu Ağagündüz; duyguturkozu@gazi.edu.tr

Received 17 November 2022; Revised 17 February 2023; Accepted 20 March 2023; Published 4 April 2023

Academic Editor: El Hassan Sakar

Deep-fried foods are among the foods that are increasing in popularity both in the food industry and in domestic applications. While these foods stand out due to their sensory properties, oxidative alterations in frying oils cause concern. This study analysed the thermo-oxidative alterations that occur during deep frying with 10 commonly used culinary oils. Deep frying processes (180 ± 5°C) were carried out with a total of one liter of each type of oil and 100-g potatoes at every turn (sliced into 1 cm $*$ 1 cm $*$ 6 cm pieces). The process was carried out keeping the conditions constant for all oils and was repeated 10 times consecutively for all oils. The malondialdehyde and peroxide values of vegetable ghee (VG) were found to be 0.669 nmol/g and 21.0 $mEqO_2$/kg, respectively, and were higher than those of other oils. Extra virgin olive oil (EVOO) (232.23) had the highest iodine value, while hazelnut oil (HO) (27.92) had the lowest value. While total polar compounds were within legal limits in all oils, they were higher (17%–23%) in EVOO, palm oil (PO), VG, and refined olive pomace oil than in other oils (17%–23%). As a result of this study, the thermo-oxidative changes in frying made with sunflower oil types are less than those of other oils, and the oxidative product/polar compound levels, which have adverse effects on health, are close to the legal limit in some oils (PO, VG, refined olive pomace, and corn oil).

1. Introduction

Deep-frying is becoming increasingly popular in industrial and home-cooked foods. It has been reported that almost half of the lunch and dinner food orders in commercial restaurants contain one or more fried products [1–3]. This increasing popularity is associated with the sensory properties of fried foods, especially colour, odour, flavor, and texture [4]. Deep-frying is a cooking process in which food is cooked by immersing it in frying oil at a temperature of approximately 150–200°C, at a depth of 20–200 mm or more, and the frying oil can be reused several times [5]. It is one of the traditional and most widely used processes for the preparation of various fried foods, especially potato chips, French fries, fish sticks, donuts, and fried chicken products [6].

Deep frying is a process involving the simultaneous transfer of heat and mass between the product and the frying oil [6]. Frying oil acts as a heat transfer medium and contributes to the texture and flavor of fried foods [7]. The frying process consisted of two stages. In the first stage, the high-temperature oil causes the water in the outer layer of the fried food to evaporate. The water in the centre of the food flows toward the outer surface, preventing the oil from entering the food and the central temperature of the food from rising above 100°C. After a certain amount of water in the fried food evaporates, the second stage begins, in which the hot oil penetrates the food and a crispy outer crust structure is formed [6, 8, 9]. This process gives fried foods an attractive smell and flavor and a golden and crispy texture.

Deep frying is a complex physicochemical process that is affected by many factors simultaneously, such as the composition of the food being fried, moisture content and amount, type of oil used in frying, frying temperature and time, intermittent or continuous heat application, and fryer model [10, 11]. Therefore, a wide variety of products emerge during this complex process. For example, frying with or without food involves different chemical reactions, and different products are produced in these oils [12]. The frying process affects the quality of both the fried food and the frying oil. The composition, size, texture, and form of the fried food may be alter because of the oil being absorbed, which could lead to a loss of nutrients, particularly vitamins [13, 14]. The physicochemical characteristics of raw potato tubers have a significant impact on the final quality of fried potato. However, the repeated heating of vegetable oils which can degrade oils can result with lipid oxidation [15]. There are new promising computer-based technologies, which will help monitor and optimize the quality of raw and processed potatoes [13].

The interaction between fried food and frying oil causes complex chemical reactions and their continuous progression. While some of these reactions, such as Maillard reactions, provide the desired colour and flavor of the product formed because of frying, some may cause nutrient losses, and the formation of some compounds have negative effects on the quality of the fried product and human health, such as aldehyde, acrylamide, and trans-configured components [16, 17]. During frying, hydrolytic alterations occur in frying oil due to the replacement of some of the water in the structure of the fried foods with edible oil, and as a result, free fatty acids (FFA), monoacylglycerols, and diacylglycerols are formed [8]. Additionally, various thermo-oxidative reactions such as oxidation due to the presence of oxygen and thermal decomposition due to high temperatures, cause the composition of the frying oil to change [12]. With the progression of these reactions, smaller reactive molecules such as hydroperoxides, epoxides, hydroxides, aldehydes, ketoacids, cyclic fatty acids, or dimeric and polymeric triacylglycerols are formed, the quality of the oil deteriorates, and alterations occur in its nutritional, sensory, and functional properties [6, 8, 18]. For this reason, it is recommended that in terms of nutrition, the ideal frying oil should contain low levels of saturated, trans, and polyunsaturated fatty acids, the precursors of unwanted oxidized and polymerized products, and high levels of oleic glycerol esters [1, 19]. Additionally, the stability of vegetable oils against oxidation varies according to their unsaturated fatty acid composition and the composition of compounds such as tocopherols, some sterols, hydrocarbons (squalene), carotenoids, polyphenols, and trace metals [5, 20].

Since the oil used during frying becomes a part of the food, the deterioration in the oil in this process also affects the flavor and nutritional value of the fried foods [1, 5, 12]. For this reason, the degree of deterioration of the frying oils should be closely monitored. The degree of deterioration and usability of frying oils is monitored by measuring properties such as acid value, peroxide value, anisidine value, conjugated diene, total polar compounds (TPC), and polymeric triglycerides (PTG). It is recommended that TPC and PTG, which are among these parameters, should not exceed 24% and 12%, respectively. In most European countries, frying oil should not be used if the TPC and PTG together exceed 24%–27% [4, 19]. Chen et al. [21] showed that the content of TPCs in soybean oil and palm olein exceeded the limit of 24% after 48 h of deep-frying. In another study, the total time for rapeseed oil to reach these rates was found to be 23.5 h, while the time for sunflower oil to degrade was 17.5 h [22].

Numerous studies have been published on the comparative performance of different oils and fats in the frying process [5, 23]. However, the results vary due to factors such as frying temperature and time, the type and composition of oil used in frying, the antioxidant composition of fried food and oil used, and the ratio of surface area to oil volume of fried foods [8]. Therefore, it is essential to compare different oil types using the same method to determine the appropriate oil type to be used in deep frying, compare the stabilization of oil types during the frying process, and prevent misinterpretations that may arise from methodological differences between studies. Based on these considerations, this research was carried out to compare the thermo-oxidative alterations in the deep-frying process in 10 reused oil types.

2. Materials and Methods

2.1. Samples. The potatoes used in the study (*Solanum tuberosum*) were purchased fresh from a local supermarket (Ankara/Turkey) according to the Ware Potatoes standard no. TS 1222 and stored in a cool (+4°C) and dark place until fried. Vegetable oils (refined olive oil (ROO), extra virgin olive oil (EVOO), omega-3 fortified sunflower oil (omega-3 SO), sunflower oil (SO), corn oil (CO), palm oil (PO), vegetable ghee (VG), hazelnut oil (HO), refined olive pomace oil (ROPO), and mixed vegetable oil (MVO)) used in the frying process were obtained from local markets and manufacturing plants before the study (Figure 1). Based on the label information of the oils, the energy and fatty acid compositions are given in Table 1. All chemicals and solvents used in this study were of analytical grade and purchased from Sigma (USA) and Merck (Germany). The solutions were prepared immediately before usage.

2.2. Frying Procedure. The raw potatoes were peeled and washed just before frying. Then, they were sliced to be equal in size (approximately 1 cm × 1 cm × 6 cm) with a manual stainless potato slicer. The sliced potatoes were washed a few times with cold water and dried with a kitchen towel and made ready for frying.

Potatoes were deep-fried using a nonstick chip pan deep fat fryer cooking pot frying basket, approximately dimensions: H9 × D24 cm and capacity 2 liters. Initially, 1 liter of oil was placed into each frying pan with a capacity of 2 liters, and temperature controls were made with digital food thermometers with probes and heated up to 180 ± 5°C.

After reaching this temperature, each potato sample (100 grams) was randomly selected and fried for 3 min. After the frying process was finished, approximately 10 ml of each oil was sampled, and the second frying process was started. In total, this frying circulation was repeated in 10 series. Before each series, the next frying was started by paying attention to the temperature of the oil at 180 ± 5°C. A sample of 10 mL was taken at the end of each frying (Figure 2). Oil

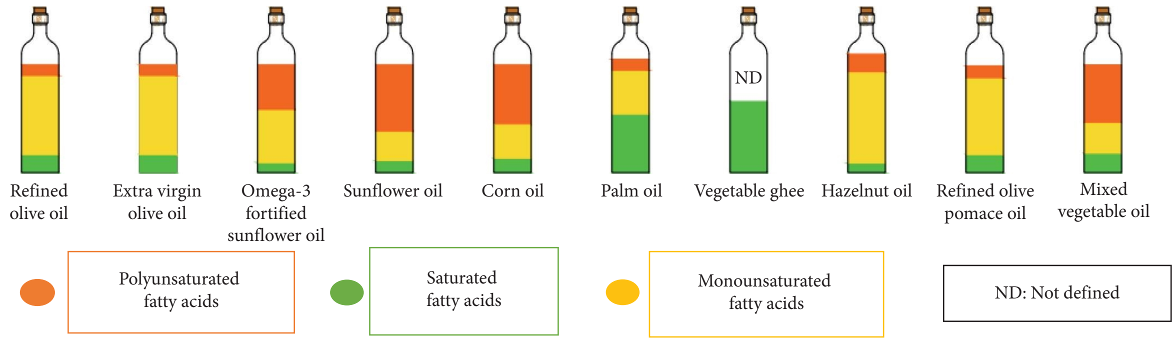

Figure 1: The fatty acid composition of the frying oils.

samples were stored in brown and sealed bottles, and analyses were carried out on the same day.

2.3. Identification of Oxidation Products

2.3.1. Total Polar Compounds (TPC). Total polar matter analysis in oil samples was performed using a commercial kit (ChemBio, USA). Analyses were performed based on the protocol specified by the manufacturer. In this method, colorimetric analysis, measurement intervals are given according to a certain colour scale. Accordingly, measurement intervals are <5%, 6%–12%, 13%–16%, 17%–23%, and >24%. Measurement at a level of 24% and above is considered unusable.

2.3.2. Peroxide Value (PV). The amount of peroxide in the oil is an indicator of the degree of deterioration of the oil and is the measure of the amount of active oxygen ($mEqO_2/kg$) in the oils. The peroxide number in the oil samples was determined under laboratory conditions without direct light. A mixture of 20 mL chloroform-acetic acid (1 : 1 v/v) and 0.5 mL potassium iodine was added to the oil sample (1 mL) taken into a clean flask and reacted in a dark environment. Next, 3 mL of starch solution (1%) was added to help free any residual iodine from the solution. Then, it was titrated with the thiosulfate standard solution (0.002 N) until the observed colour was gone. The same operations were performed for the blank sample, and calculations were made. Finally, PV was calculated with the following equation:

$$\text{PV} = \frac{(\text{mL of sodium thiosulfate x normality of the sodium thiosulfate})}{\text{Weight of lipid x 1000}}. \quad (1)$$

2.3.3. Iodine Value (IV). The iodine number indicates the degree of unsaturation of a fat or oil [24]. As the deterioration of vegetable oils progressed, the iodine values decrease accordingly. The iodine number in the oil samples was determined under laboratory conditions without direct light. 1 mL of oil sample was taken into a clean flask, 5 mL chloroform was added to it, and the oil was melted with gentle rotational movements. When the oil melted, 8 mL IBr was added to it and it was kept covered in a dark place for 1 h. After 1 h, 7 mL KI and 30 mL water were added, and then the mixture was titrated with 0.1 N $Na_2S_2O_3$ by using 0.5 mL of starch solution (1.0%) as an indicator until the yellow is gone after shaking vigorously. Calculations were made by performing the same operations for the blank sample. For final calculations of IV of oil samples, the following equation was used:

$$\text{IV} = 12.69 \text{ x } \frac{(\text{mL of Blank} - \text{mL of Sample or Weight of Sample})}{\text{mL of sample or Weight of Sample}}. \quad (2)$$

2.3.4. Malondialdehyde (MDA) Levels. The MDA level was determined by a method as described elsewhere which is based on the reaction with thiobarbituric acid (TBA) at 90–100°C [25]. In the TBA test reaction, MDA or MDA-like substances and TBA react with the production of a pink pigment with maximum absorption at 532 nm. The reaction was performed at pH 2-3 at 90°C for 15 min. The sample was mixed with two volumes of cold 10% (w/v) trichloroacetic acid. The precipitate was pelleted after centrifugation, and an aliquot of the supernatant reacted with an equal volume of 0.67% (w/v) TBA in a boiling water bath for 10 min. After cooling, the absorbance was read at 532 nm. The results were expressed as nmol/g (Relassay, Turkey).

2.4. Statistical Analysis. The oil type and the number of series frying are important and affect the oxidation of the oil. The fatty acid composition of the oil, the quality of the oil, and storage condition of the oil are the main factors that can

TABLE 1: The fatty acid composition of the oils used in the present study.

Type of oil	Company	Nutrition facts	Energy (kcal)	Total fat (g)	SFA (g)	MUFA (g)	PUFA (g)
Refined olive oil	A	ND	819	91	15	67	9
Extra virgin olive oil	A	ND	819	91	15	67	9
Omega-3 fortified sunflower oil	A	70% sunflower oil, 30% canola oil, flavoring agent, and ND about omega-3	819	91	8.3	45	37.7
Sunflower oil	A	ND	819	91	10	25	56
Corn oil	B	ND	819	91	12	28	51
Palm oil*	C	ND	884	100	49.3	37	9.3
Vegetable ghee	D	Palm oil, butter flavor, vitamin A, vitamin D, and colouring agent(beta carotene)	900	99.9	60	ND	ND
Hazelnut oil	E	Refined hazelnut oil	895	100	8	77	15
Refined olive pomace oil	F	ND	819	91	15	65	10
Mixed vegetable oil	G	Sunflower oil, cottonseed oil, and antioxidant	819	91	16.2	26	48.7

Note: SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; ND: not defined; *USDA.

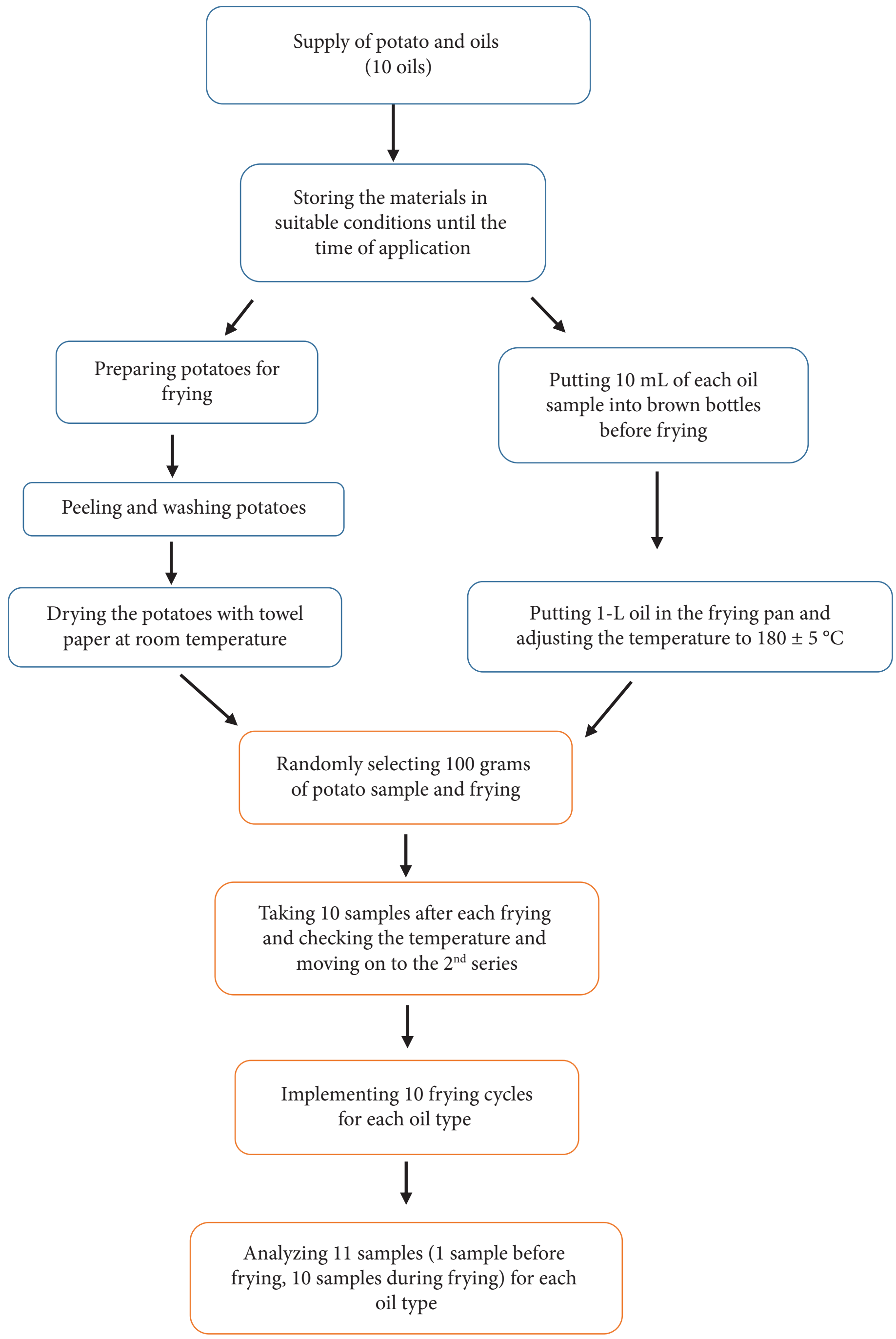

Figure 2: Flowchart of sample preparation and analysis.

affect oxidation. Also, temperature and amount of sample are among the factors, which influence the oil deterioration. However, the number of series frying is also significant since after a specific point (which can be different for each oil) advanced oxidation products can be obtained. Reusing frying oil results in the production of additional free fatty acids, PV, saturated fatty acids, and trans fatty acids [15, 26]. Based on this data, this study was planned to examine the oxidative changes of different vegetable oils during domestic deep-frying and tried answering the following questions: (i) Which oil types provides the best organoleptic properties in fried potatoes? (ii) Which oil types undergoes less oxidative changes in frying? (iii) Is it possible to identify a type of oil that does not pose a health risk for domestic frying?

SPSS Statistics for Windows, Version 22.0, and Microsoft Excel 2020 programs were used in the analysis of the data. Repeated measures ANOVA test was performed in the statistical analysis of the oils used in frying. The Bonferroni

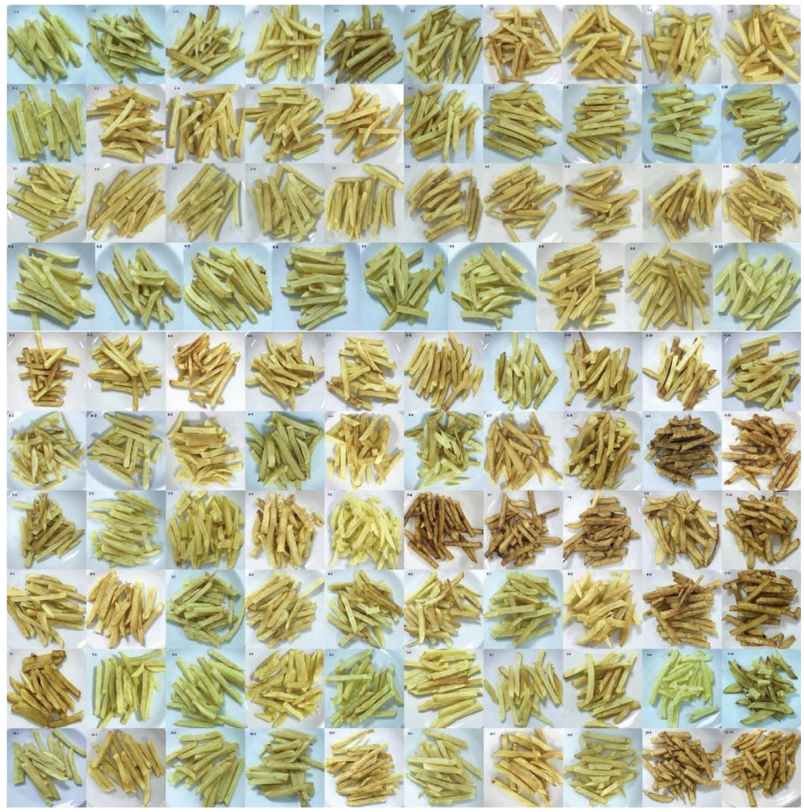

Figure 3: The fried potatoes with different types of oils.

method was performed to examine whether there was a difference between the first, fifth, and tenth fries, and multiple comparisons were made between the three tests. $p < 0.05$ was considered a statistically significant difference in all tests.

3. Results

The organoleptic properties of fried potatoes were subjectively investigated after completing the frying process. At the end of each frying, fried potatoes made with each oil type were photographed on plates of the same size and colour and given together in Figure 3. Potatoes fried in PO, HO, and MVO showed a distinct colour change (from golden yellow to brown) after the eighth frying. A similar colour change was observed after the fifth frying with VG.

In the frying process with ten different oil types, samples were taken at the baseline (untreated oil) and the end of each frying, and analyses were carried out with 11 samples for each oil type. Oxidative alterations in oils are summarized in Table 2. The IV of the oils showed some alterations during frying. Accordingly, the IV of some oil types (EVOO, SO, and PO) increased after frying, while the IV of some oil types (ROO, Omega-3 SO, CO, VG, HO, ROPO, and MVO) decreased. However, peroxide values of oils (except SO) increased during frying. At the end of the tenth frying, the oil with the highest peroxide value was found to be VG (21.0 mEqO_2/kg), while the lowest oil types were EVOO (9.4 mEqO_2/kg) and Omega-3 SO (9.4 mEqO_2/kg). In the baseline, the peroxide value of SO (16.0 to 9.4 mEqO_2/kg) was higher than that of other oils, while the peroxide value of HO was 2.2 mEqO_2/kg, which is lower than that of other oils (Table 2).

According to the total polar substance analysis with each oil type at the end of frying, the polar substance content of EVOO, PO, VG, and ROPO was found to be higher than the other oil types (17%–23%). While the total polar substance content of ROO, Omega-3 SO, SO, and HO were measured as <5%, CO and MVO oil types were determined as 6%–12%.

MDA (nmol/g) values of oil types generally increased during frying. While the MDA values of SO in the baseline (0.069 ± 0.009 nmol/g) and the end of frying (0.105 ± 0.004 nmol/g) were lower than that of other oil types, the MDA values of VG were determined to be the highest in the baseline (0.493 ± 0.005 nmol/g), during (0.693 ± 0.005 nmol/g) and at the end of frying (0.660 ± 0.009 nmol/g). The frying process showed that after VG, CO was the second highest type of oil with an MDA of 0.275 ± 0.004 nmol/g at the end of the frying. Although the MDA value of EVOO slightly decreased during frying, it was observed that the MDA value of ROO increased at the end of frying (0.154 ± 0.011 nmol/g).

Table 2: Oxidative alterations in different oil type during frying.

Oils	ROO	EVOO	Omega-3 SO	SO	CO	PO	VG	HO	ROPO	MVO	p^*
Iodine value											
Baseline	170.07 ± 0.027	203.05 ± 0.012	195.43 ± 0.014	159.93 ± 0.062	223.34 ± 0.003	184.01 ± 0.015	203.04 ± 0.052	190.35 ± 0.008	234.75 ± 0.007	180.19 ± 0.005	
5th frying	184.02 ± 0.024	215.73 ± 0.072	123.03 ± 0.054	220.81 ± 0.012	223.31 ± 0.054	237.28 ± 0.030	181.46 ± 0.004	158.61 ± 0.019	213.21 ± 0.038	60.90 ± 0.008	0.717
10th frying	190.35 ± 0.004	232.23 ± 0.011	114.20 ± 0.005	185.27 ± 0.004	145.94 ± 0.006	209.38 ± 0.008	164.96 ± 0.013	27.92 ± 0.010	228.42 ± 0.006	140.86 ± 0.446	
Peroxide value ($mEqO_2/kg$)											
Baseline	7.3 ± 0.005	3.8 ± 0.005	3.6 ± 0.004	6.4.0 ± 0.004	3.0 ± 0.011	4.8 ± 0.008	8.4 ± 0.006	2.2 ± 0.003	13.2 ± 0.010	6.6 ± 0.003	
5th frying	7.6 ± 0.003	8.2 ± 0.004	5.2 ± 0.003	21.0 ± 0.004	7.4 ± 0.003	6.6 ± 0.004	14.2 ± 0.006	7.6 ± 0.002	10.0 ± 0.004	6.8 ± 0.005	**0.002**
10th frying	12.0 ± 0.003	9.4 ± 0.005	9.4 ± 0.001	7.4 ± 0.012	16.0 ± 0.034	14.4 ± 0.004	21.0 ± 0.007	11.2 ± 0.004	14.8 ± 0.005	11.0 ± 0.005	
Malondialdehyde (nmol/g)											
Baseline	0.106 ± 0.003	0.142 ± 0.004	0.125 ± 0.004	0.069 ± 0.009	0.161 ± 0.003	0.174 ± 0.004	0.493 ± 0.005	0.178 ± 0.004	0.245 ± 0.005	0.095 ± 0.004	
5th frying	0.140 ± 0.005	0.117 ± 0.003	0.102 ± 0.003	0.080 ± 0.005	0.162 ± 0.005	0.153 ± 0.006	0.693 ± 0.005	0.214 ± 0.005	0.247 ± 0.003	0.114 ± 0.008	0.452
10th frying	0.154 ± 0.011	0.117 ± 0.002	0.122 ± 0.002	0.105 ± 0.004	0.275 ± 0.004	0.203 ± 0.005	0.660 ± 0.009	0.175 ± 0.004	0.234 ± 0.004	0.134 ± 0.006	
TPC (%)	<5	17–23	<5	<5	6–12	17–23	17–23	<5	17–23	6–12	—

*Friedman test. Refined olive oil (ROO); extra virgin olive oil (EVOO); omega-3 fortified sunflower oil (omega-3 SO); sunflower oil (SO); corn oil (CO); palm oil (PO); vegetable ghee (VG); hazelnut oil (HO); refined olive pomace oil (ROPO); mixed vegetable oil (MVO); total polar compounds (TPC). The bold value indicates that the p value is less than 0.05.

4. Discussion

Deep frying, a widely used cooking method today, is an ancient cooking method dating back to 1600 BC. 180°C is generally recommended for frying food, but the temperature can often rise above 180°C in deep frying. Various reactions such as oxidation, isomerization, hydrolysis, and polymerization, occur during deep-frying [12, 27]. Frying conditions, such as temperature (time, equipment used in frying, etc.), the type of oil used in frying, and the structure of the fried food are the main factors affecting these reactions [15, 26]. For this reason, in this study, the oxidative alterations occurring in the frying process were compared in ten oil types used repeatedly, ensuring equality in all conditions except the oil type. It has been shown that the organoleptic properties of potatoes fried with PO, WG, Ho, and MVO are more undesirable than other oil types. Fewer desirable results were obtained in VG than other oil types in terms of thermo-oxidative alterations of potatoes, and more desirable results from frying processes using SO.

The iodine value is a parameter used to express the degree of unsaturation or the average number of double bonds of fatty acids in fats and oils [28]. The iodine value is a method used in the oil industry to roughly evaluate the oxidative stability of edible oils and fats [29]. The decrease in the iodine value is an indicator of the oxidation of the oil, as well as the decrease in the number of double bonds [28]. In a study using five different oil types (standard refined sunflower oil, palm olein, standard refined sunflower oil with synthetic antioxidant, standard refined sunflower oil with rosemary extract, and high oleic refined sunflower oil), there was a significant decrease in IV in palm olein (57.28 ± 0.87 g/100 g) and high oleic sunflower oil (85.25 ± 1.26 g/100 g) because of frying, while there was no significant change in the IV of other oil types [28].

The oxidative alterations in oils after frying different foods with five different oils (palm, corn, peanut, soybean, and sunflower) were investigated, and a decrease in the iodine value of all oil types was observed. When the oils were compared, a greater decrease was observed in IV in soybean oil than in other types of oil [30]. During deep frying, IV reduction is observed because as the oil oxidizes, the number of double bonds decreases, and therefore, IV decreases, too. In this study, it was determined that IV decreased in many types of oil (ROO, Omega-3 SO, CO, VG, HO, ROPO, and MVO) after frying ($p > 0.05$). This result suggests that many types of culinary oil oxidize after the tenth frying.

The deterioration in oil during frying affects the flavor and nutritional value of fried foods. Therefore, it is important to monitor alterations in the quality of the frying oils. The degree of deterioration and reusability of frying oils can be monitored using some physical (colour, odour, and viscosity) and chemical (TPC, PTG peroxide value, p-anisidine value, etc.) parameters [31]. TPC is a widely used method for evaluating the quality of frying oils, and it is recommended not to exceed 24%–27% [32]. The TPC limit in Turkish frying oils has been determined as 25% [33]. Yu et al. [31] repeatedly fried potatoes with a total of four oil types: vegetable shortening, refined soybean oil, pure olive oil, and refined coconut oil. The TPC value of oils was reported to be 8.1%–9.5% after 80 cycles. In another study, the rate of TPC formation in palm olein during frying was found to be lower than that in soybean oil in 8 cycles of frying. PC is related to the type of oil rather than the type of fried food, and although the formation of TPC during frying was lower in palm olein, it reached the legal limit (25%) faster [21] in the mixture of ROPO and ROPO-refined coconut oil (80:20) [34]. At the end of frying (60 times), the ROPO-RCO mixture exhibited higher chemical stability than ROPO in terms of TPC and polymers. The TPC of the blended oil was 23.3%, while the ROPO was reported to be 30.6% [34]. In a relevant study, two rapeseed oils with different oleic acid compositions were stored at different temperatures (room temperature and refrigerator temperature) and subjected to a deep-frying process, and the effect of these factors on the degradation rate of oil was investigated. The results showed that oil containing high oleic acid reached 24% TPC after 22 h of frying when stored at room temperature and 26 h when stored at refrigerator temperature. In low oleic acid oil, these durations were found to be 19 and 22.5 h, respectively [35].

In a study, some foods of both vegetable and animal origin which were deep-fried and pan-fried using different frying oils (sunflower oil, cottonseed oil, corn oil, palm oil, palm kernel oil, soybean oil, and vegetable shortening) were collected, and their TPC and PTG values were collected [35]. Because of this study, the highest TPC and PTG values were observed in the use of palm oil, palm kernel oil, vegetable shortening, soybean oil, and fried foods of animal origin [23]. In this study, the TPC value of ROPO, EVOO, PO, and VG oils was higher than other oils and was calculated as 17%–23%. The TPC of CO and MVO is 6%–12%, while the TPC of ROO, Omega-3 SO, SO, and HO is <5%. Because of 10 repeated frying processes, although TPC is high in some oils, TPC of all oils is still within legal limits. Factors such as frying temperature, time, the number of frying cycles, the type and composition of oil used in the frying, and the antioxidant composition of the oil used/containing artificial antioxidants cause the results of the studies to be different. However, the TPC levels of oils generally increase as the number of frying cycles increases.

The peroxide value is a widely used chemical method that measures the oxidative degradation of oils. PV only shows the number of primary products [36]. However, PV may not reflect the true extent of lipid oxidation, as hydroperoxides are easily broken down into secondary products. For this reason, TBA is often used to measure secondary oxidation products. Specifically, TBA measures the concentration of MDA, a secondary reaction product, and a reactive aldehyde [37]. In this study, peroxide and MDA values of frying oils were analysed. All oils except SO increased because of PV frying, while SO baseline PV was lower than the 5^{th} frying. However, an increase was observed in the MDA value of SO during frying. The formation of MDA from lipid oxidation reactions may be the cause of PV reduction. The oil with the highest MDA value in the baseline and during frying is VG, followed by corn oil. According to a recent publication, the PV of olive oils has been reported to be ≤20 $mEqO_2$/kg [38]. In this study, even after the 10th frying, the PV of both ROO and EVOO remained within the limit. Park and Kim [39] performed a frying process (101 cycles) with four different types of oil (soybean oil, canola oil, palm oil, and lard) and observed an increase in PV of all oil types at the end of frying. The highest increase in PV was in lard and soybean oil, whereas the lowest increase was in palm oil The PV of the oils was investigated after 80 cycles of frying with four vegetable oils: palm olein, red palm olein, sunflower oil, and soybean oil, and it was reported that although the PV of the oils increased at the baseline, the PV decreased during frying [35]. Accordingly, a decrease in PV was observed after the 48th frying with palm olein, the 32nd frying with soybean oil, the 16th frying with red palm olein, and 16th frying with sunflower oil. Besides the composition of the oils, the number of frying cycles influences the PV [35].

5. Conclusion

For many years, fried foods and frying oils have become frequently addressed topics in the literature as well as among consumers and the food industry. Researchers especially tried determining the thermo-oxidative alterations that occur in oils and to determine the oil types that best affect the sensory properties of fried foods. In addition to the oil types used for many years, new oil types to be used in frying processes are becoming increasingly common with some innovative approaches. In this study, in the domestic deep-frying process with 10 vegetable oils, fewer desirable results were obtained in VG than that in other oil types in terms of both sensory properties and thermo-oxidative alterations of potatoes, and more desirable results from frying processes using SO. Although EVOO is a type of oil rich in phenolic compounds than other monounsaturated oils, PV tended to increase during frying but remained within limits. In terms of health, even if the TPC occurring in frying oils is close to the recommended frying limits, its negative effects on the composition of fried potatoes should be investigated. On the other hand, it was also surprising that some refined oils had higher PV values compared to the unrefined counterparts. This made us think that the refined ones in new generation oils may show different oxidative properties and that different properties of the oils may be effective in oxidation as well as the refining process.

Even though this study provides significant results, there are some limitations that should be emphasized for future studies. First, this study included oils that are commonly used for domestic purposes. Since cuisine and food culture vary widely, the types of oil used in frying are not limited to the types that were analysed in this study. However, in this study, frying process was repeated 10 times on the same day and analysed the oils under constant conditions. However, frying oils can be used multiple times (>10 times) and can be stored and reused in the following days. It would be useful to analyse oils after using them in the following days. There are also some concerns with the reuse of frying oil after it has been stored for a period. Finally, this study did not cover all parameters that are related to the oxidation of the oils. Therefore, further studies with sensory analyses and other instrumental methods are needed to analyse the effects of storage time on oils and fried foods.

Data Availability

The data supporting the conclusions of the article are included in the article, and the database is available from the corresponding author (duyguturkozu@gazi.edu.tr) upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yilmaz B. and Sahin T.O drafted the work and revised it critically for important intellectual content and final approval of the version to be published. Duygu A. designed and drafted the work and revised it critically for important intellectual content and final approval of the version to be published. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors would like to thank undergraduate students and teaching assistants who did not meet the conditions for authorship but helped in the frying of potatoes.

References

[1] A. Mariod, B. Matthäus, K. Eichner, and I. H. Hussein, "Frying quality and oxidative stability of two unconventional oils," *Journal of the American Oil Chemists' Society*, vol. 83, no. 6, pp. 529–538, 2006.

[2] M. F. Ramadan, "Rapid antiradical method for screening deep fried oils," *Journal für Verbraucherschutz und Lebensmittelsicherheit*, vol. 5, no. 1, pp. 47–50, 2010.

[3] E. Aydınkaptan and I. Barutçu Mazı, "Monitoring the physicochemical features of sunflower oil and French fries during repeated microwave frying and deep-fat frying," *Grasas Y Aceites*, vol. 68, no. 3, pp. e202–e, 2017.

[4] N. K. Andrikopoulos, G. V. Dedoussis, A. Falirea, N. Kalogeropoulos, and H. S. Hatzinikola, "Deterioration of natural antioxidant species of vegetable edible oils during the domestic deep-frying and pan-frying of potatoes," *International Journal of Food Sciences & Nutrition*, vol. 53, no. 4, pp. 351–363, 2002.

[5] S. Karakaya and S. Şimşek, "Changes in total polar compounds, peroxide value, total phenols and antioxidant activity of various oils used in deep fat frying," *Journal of the American Oil Chemists' Society*, vol. 88, no. 9, pp. 1361–1366, 2011.

[6] S. Asokapandian, G. J. Swamy, and H. Hajjul, "Deep fat frying of foods: a critical review on process and product parameters," *Critical Reviews in Food Science and Nutrition*, vol. 60, no. 20, pp. 3400–3413, 2020.

[7] E. Choe and D. B. Min, "Chemistry of deep-fat frying oils," *Journal of Food Science*, vol. 72, no. 5, pp. R77–R86, 2007.

[8] A. Chiou and N. Kalogeropoulos, "Virgin olive oil as frying oil," *Comprehensive Reviews in Food Science and Food Safety*, vol. 16, no. 4, pp. 632–646, 2017.

[9] G. Gholamibozanjani, S. Y. Leong, I. Oey, P. Bremer, P. Silcock, and M. Farid, "Heat and mass transfer modeling to predict temperature distribution during potato frying after pre-treatment with pulsed electric field," *Foods*, vol. 10, no. 8, p. 1679, 2021.

[10] L. Brühl, "Fatty acid alterations in oils and fats during heating and frying," *European Journal of Lipid Science and Technology*, vol. 116, no. 6, pp. 707–715, 2014.

[11] F. A. Aladedunye, "Curbing thermo-oxidative degradation of frying oils: current knowledge and challenges," *European Journal of Lipid Science and Technology*, vol. 117, no. 11, pp. 1867–1881, 2015.

[12] Q. Zhang, A. S. M. Saleh, J. Chen, and Q. Shen, "Chemical alterations taken place during deep-fat frying based on certain reaction products: a review," *Chemistry and Physics of Lipids*, vol. 165, no. 6, pp. 662–681, 2012.

[13] A. Arefi, O. Hensel, and B. Sturm, "Intelligent potato frying: time to say goodbye to the "good old" processing strategies," *Thermal Science and Engineering Progress*, vol. 34, Article ID 101389, 2022.

[14] J. C. Lumanlan, W. M. A. D. B. Fernando, and V. Jayasena, "Mechanisms of oil uptake during deep frying and applications of predrying and hydrocolloids in reducing fat content of chips," *International Journal of Food Science and Technology*, vol. 55, no. 4, pp. 1661–1670, 2020.

[15] A. Tadesse Zula and T. Fikre Teferra, "Effect of frying oil stability over repeated reuse cycles on the quality and safety of deep-fried Nile tilapia fish (*Oreochromis niloticus*): a response surface modeling approach," *International Journal of Food Properties*, vol. 25, no. 1, pp. 315–325, 2022.

[16] M. Starowicz and H. Zieliński, "How maillard reaction influences sensorial properties (color, flavor and texture) of food products?" *Food Reviews International*, vol. 35, no. 8, pp. 707–725, 2019.

[17] K. Bordin, M. T. Kunitake, K. K. Aracava, and C. S. F. Trindade, "Changes in food caused by deep fat frying--a review," *Archivos Latinoamericanos de Nutricion*, vol. 63, no. 1, pp. 5–13, 2013.

[18] E. De Marco, M. Savarese, C. Parisini, I. Battimo, S. Falco, and R. Sacchi, "Frying performance of a sunflower/palm oil blend in comparison with pure palm oil," *European Journal of Lipid Science and Technology*, vol. 109, no. 3, pp. 237–246, 2007, https://doi.org/10.1002/ejlt.200600192.

[19] F. D. Gunstone and S. Martini, "14 - chemical and physical deterioration of bulk oils and shortenings, spreads and frying oils," in *Chemical Deterioration and Physical Instability of Food and Beverages*, L. H. Skibsted, J. Risbo, and M. L. Andersen, Eds., pp. 413–438, Woodhead Publishing, Sawston, UK, 2010.

[20] S. Casal, R. Malheiro, A. Sendas, B. P. Oliveira, and J. A. Pereira, "Olive oil stability under deep-frying conditions," *Food and Chemical Toxicology*, vol. 48, no. 10, pp. 2972–2979, 2010.

[21] W.-A. Chen, C. P. Chiu, W.-C. Cheng, C.-K. Hsu, and M. I. Kuo, "Total polar compounds and acid values of repeatedly used frying oils measured by standard and rapid methods," *Journal of Food and Drug Analysis*, vol. 21, no. 1, 2013.

[22] L. Zeleňáková, M. Angelovičová, M. Šnirc et al., "Thermodegradative changes of rapeseed and sunflower oils during deep-frying French fries," *Potravinarstvo Slovak Journal of Food Sciences*, vol. 13, no. 1, pp. 138–149, 2019.

[23] N. K. Andrikopoulos, G. Boskou, G. V. Z. Dedoussis, A. Chiou, V. A. Tzamtzis, and A. Papathanasiou, "Quality assessment of frying oils and fats from 63 restaurants in Athens, Greece," *Food Service Technology*, vol. 3, no. 2, pp. 49–59, 2003.

[24] S. Gharby, A. Hajib, M. Ibourki et al., "Induced changes in olive oil subjected to various chemical refining steps: a comparative study of quality indices, fatty acids, bioactive minor components, and oxidation stability kinetic parameters," *Chemical Data Collections*, vol. 33, Article ID 100702, 2021.

[25] Z. Kurcer, E. Oğuz, M. Iraz et al., "Melatonin improves methanol intoxication induced oxidative liver injury in rats," *Journal of Pineal Research*, vol. 43, no. 1, pp. 42–49, 2007.

[26] M. D. A. Saldaña and S. I. Martínez-Monteagudo, "Oxidative stability of fats and oils measured by differential scanning calorimetry for food and industrial applications," in *Applications of Calorimetry in a Wide Context*, E. Amal Ali, Ed., IntechOpen, Rijeka, Croatia, 2013.

[27] A. Mariod, N. Omer, E. Al, and M. M. Mariod, "Chemical reactions taken place during deep-fat frying and their products: a review," *Sudan University of Science & Technology SUST Journal of Natural and Medical Sciences*, pp. 1–17, 2014.

[28] R. Romanić, T. Lužaić, and K. Grgić, "Examining the possibility of improving the properties of sunflower oil in order to obtain a better medium for the process of frying food," *The 1st International Electronic Conference on Food Science and Functional Foods*, vol. 70, p. 104, 2020.

[29] N. C. Bitkisel, "Yağların muhafazasında oksidatif stabilitenin önemi ve oksidatif stabilitenin belirlenmesinde kullanılan analiz yöntemleri," *Anadolu Bil Meslek Yüksekokulu Dergisi.*vol. 14, no. 54, pp. 107–124, 2019.

[30] J. Chebet, T. Kinyanjui, and P. K. Cheplogoi, "Impact of frying on iodine value of vegetable oils before and after deep frying in different types of food in Kenya," *Journal of Scientific and Innovative Research*, vol. 5, 2016.

[31] K. S. Yu, H. Cho, and K. T. Hwang, "Physicochemical properties and oxidative stability of frying oils during repeated frying of potato chips," *Food Science and Biotechnology*, vol. 27, no. 3, pp. 651–659, 2018.

[32] H. Hosseini, M. Ghorbani, N. Meshginfar, and A. S. Mahoonak, "A review on frying: procedure, fat, deterioration progress and health hazards," *Journal of the American Oil Chemists' Society*, vol. 93, no. 4, pp. 445–466, 2016.

[33] Anonymous Tc Cumhurbaşkanliği Mevzuat Bilgi Sistemi, "Kızartmada kullanılmakta olan katı ve sıvı yağlar i?çin özel hijyen kuralları yönetmeliği," 2021, https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=16138&MevzuatTur=7&MevzuatTertip=5.

[34] I. Ben Hammouda, M. Triki, B. Matthäus, and M. Bouaziz, "A comparative study on formation of polar components, fatty acids and sterols during frying of refined olive pomace oil pure and its blend coconut oil," *Journal of Agricultural and Food Chemistry*, vol. 66, no. 13, pp. 3514–3523, 2018.

[35] L. Zeleňáková, S. Pastyriková, R. Židek, and L. Mura, "Comparison of the quality of vegetable oils designed for the frying food," *Potravinarstvo Slovak Journal of Food Sciences*, vol. 6, no. 4, pp. 45–51, 2012.

[36] F. Kong and R. P. Singh, "12 - advances in instrumental methods to determine food quality deterioration," in *Food and Beverage Stability and Shelf Life*, D. Kilcast and

P. Subramaniam, Eds., pp. 381–404, Woodhead Publishing, Sawston, UK, 2011.

[37] F. Kong and R. P. Singh, "8 - advances in instrumental methods for shelf life evaluation," in *The Stability and Shelf Life of Food*, P. Subramaniam, Ed., pp. 229–251, Woodhead Publishing, Sawston, UK, 2016.

[38] S. El Hassan and G. Said, "Olive oil: extraction technology, chemical composition, and enrichment using natural additives," in *Olive Cultivation*, Y. Taner, Ed., IntechOpen, Rijeka, Croatia, 2022.

[39] J.-M. Park and J.-M. Kim, "Monitoring of used frying oils and frying times for frying chicken nuggets using peroxide value and acid value," *Korean Journal for Food Science of Animal Resources*, vol. 36, no. 5, pp. 612–616, 2016.