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Impact of deep-fat frying cycles on the physicochemical characteristics of two edible vegetable oils marketed in Algeria

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ABSTRACT

Background: Vegetable oils containing polyunsaturated fatty acids are prone to oxidation when exposed to high-temperature frying processes. **Aims:** This study aims to follow the changes that occur in frying oil when used to fry potatoes. **Material and Methods:** The impact of the ratio of potatoes (g) to oil (g) as well as the number of frying cycles on the quality of two commonly marketed oils in Algeria: 100% soybean oil (oil A) and a blend of 60% soybean, 20% sunflower, and 20% corn oil (oil B) was assessed. The quality of these oils throughout repeated frying cycles was monitored by analyzing pH, density, color, moisture, acidity, peroxide value, saponification value, and acid index. **Results:** The results of the present study revealed that both oils experienced deterioration as the frying cycles were repeated, with more significant degradation observed with the 1/5 ratio of fries to oil compared to the 1/8 ratio. Remarkably, the 100% soybean oil deteriorated more rapidly than the oil blend. **Conclusion:** Based on the observed changes in physicochemical parameters and chemical indices, the use of frying oils beyond the third cycle significantly compromises their quality and safety. This not only impacts the consumer's health but also the organoleptic properties of fried foods. Therefore, it is highly recommended to refrain from exceeding this limit to ensure optimal frying practices and protect consumer health.

Keywords: Vegetable oils, deep-fat frying, ratio of fries/volume of oil, physical quality, chemical indices.

ARTICLE INFORMATION

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1 Introduction

Edible vegetable oils (in liquid state) and fats (in solid state) are one of the main constituents of food used for culinary preparations. Lipids play a crucial role in the diet by supplying essential fatty acids such as linoleic acid (n-6) and alpha-linolenic acid (n-3) necessary for providing the energy required for the body [1]. One of the principal utilization of fats in cooking is frying. Indeed, frying is a complex process involving heat, mass, and momentum transfers that modify the physical and chemical state of food [2]. According to Zaghi et al. [3], frying is one of the most popular methods of food preparation used in homes, restaurants, and the food industry.

Deep-fat frying is based on immersing food in hot oil, leading to its dehydration. The frying process is intended to produce acceptable food products with a crispy texture, an aromatic flavor, and a golden-brown color. Nevertheless, the consumption of fried foods can present multiple issues due to the formation of harmful compounds like acrylamide, polymers, dimers, free fatty acids, and oxidized fatty acids, along with their high caloric content [3,4].

Furthermore, frying reduces the antioxidant content of oil, leading to the excessive generation of free radicals and lipid peroxidation. These free radicals are known to cause various pathological conditions, including atherosclerosis, aging, cardiac and cerebral ischemia, nephrites, cancer, rheumatic diseases, diabetes mellitus, and adult respiratory distress syndrome [5]. Previous scientific reports have pointed out the potential adverse health effects associated with the consumption of heated oil after frying. In a study conducted by Ng et al. [6], it was observed that blood pressure of rats was not affected by fresh soybean oil. However, prolonged consumption of soybean oil that had been repeatedly heated resulted in elevated blood pressure. This effect could be attributed to increased inflammation, leading to altered prostanoid production and adverse vascular remodeling [7,8]. The consumption of oxidized products resulting from the repeated use of cooking oils in frying processes can pose potential health risks. Unfortunately, it has been observed that in many households, vegetable oils are reused 3 – 6 times before disposal in an effort to economize. The repeated use of edible oils for frying initiates several oxidative and thermal reactions, altering the physicochemical, nutritional, and sensory properties of vegetable oils. The extent of these changes in the oil's physical and chemical properties plays a critical role in determining its suitability for human consumption.

In addition, previous researchers have also highlighted changes that take place in the oil during frying, including hydrolysis, oxidation, and polymerization processes that can affect the composition, taste, and stability of vegetable oils [9,10]. These alterations yield degraded components in vegetable oils, which encompass free fatty acids, hydroperoxides, and polymerized triacylglycerols.

Various physicochemical parameters are used to monitor the quality of oils during the frying process. These parameters include acidity, pH, moisture content, color, density, saponification index (SI), and peroxide index (PI). Thus, the main objective of this study is to evaluate the impact of repeated frying and the quantitative ratio of oil to fried food (potatoes) on the physical and chemical characteristics of two types of oils: 100% soybean oil and a blend of sunflower oils, soy, and maize, widely marketed in Algeria.

2 Material and Methods

2.1 Oil samples

This study focused on two widely consumed brands of vegetable edible oil in Algeria, both refined by Algerian companies. These oils are readily available in the market and are known for their affordability compared to olive oil, making them popular choices among consumers. The first oil is 100% soybean oil while the second is a blend of soybean (60%), sunflower (20%), and corn (20%) oils. The samples were acquired in 5 – liter bottles made of polyethylene terephthalate from a local supermarket in the district of Annaba (North-East of Algeria). To maintain their integrity, the samples were left in their original packaging shielded from light, and stored at ambient temperature until analysis. Both physical and chemical features of the two oils were determined.

2.2 Frying procedure

2.2.1 Fries' preparation

The potato tubers (*Solanum tuberosum*) (10 kg) were purchased from the local market in the District of El-Tarf situated in the northeastern region of Algeria. The potatoes were meticulously peeled and manually cut ensuring the uniformity of each piece with identical dimensions of 1 x 12 x 1 cm. Subsequently, the potato sticks were rinsed with water and carefully wiped using absorbent paper.

2.2.2 Frying

In order to maintain a constant temperature (180 °C) during all 8 frying cycles, a domestic electric fryer with a 4-liter capacity was employed. The fryer featured a removable lid, a thermal circuit breaker, an adjustable thermostat, and a basket with a capacity of 1 Kg of fresh potatoes.

Importantly, no additional fresh oil was introduced during the frying process. Instead, the quantity of fresh potatoes placed in the oil bath was gradually reduced over the course of the frying cycles to match the amount of oil in order to maintain a constant ration of fresh potatoes to oil (w/w). Two rations were tested: the 1/5 ratio and the 1/8 ratio. The experimental conditions set throughout our experiment are shown in Table 1.

Table 1. Experimental conditions of the frying tests

Type of oil	"Oil A" and "Oil B"
Frying process	Deep-fat frying
Number of ratios	2 (1 /5 and 1/8)
Frying cycles	32 (at the rate of 8 frying per ratio and per type of oil)
Frying temperature	180°C
Shape of potato slices	Stick shape
Fries dimension	1x12x1cm
Oil samples volume for analysis	220 mL
Total number of samples analyzed	16 + 2 sample of fresh oils

The calculation of the 1/5 and 1/8 ratios (ratio of fresh potatoes to oil (w/w)) during frying are shown in the tables below. In all, eight frying cycles were carried out.

Table 2. Ratio of the amount of fresh potatoes to the oil quantity

	"1/5" ratio				"1/8" ratio			
	Oil-A		Oil-B		Oil-A		Oil-B	
Frying number	Oil quantity (g)	Fresh potatoes quantity (g)	Oil quantity (g)	Fresh potatoes quantity (g)	Oil quantity (g)	Fresh potatoes quantity (g)	Oil quantity (g)	Fresh potatoes quantity (g)
1	2486	497	2266	453.2	2486	310	2266	283
2	2268	453	2068	413	2268	281	2068	258
3	2038	407	1868	373.6	2083	260	1868	233
4	1838	367	1673	334.6	1838	230	1673	209
5	1638	327	1473	294.6	1638	205	1473	184
6	1448	289	1288	257.6	1448	181	1288	161
7	1243	248	1103	220.6	1243	156	1103	137
8	1048	209	878	175	1048	131	878	110

Oil-A: 100% soybean oil; Oil-B: blend of 60% soybean, 20% sunflower, and 20% corn oil

2.3 Oil sample recovery

After each frying cycle, 220 mL of oil was taken after homogenization of the frying bath. The collected oil was carefully filtered and immediately transferred to glass containers. After cooling to room temperature in a dark environment, the oils were stored in a refrigerator. The oils from the 1st, 4th, 6th, and 8th frying baths were analyzed, in addition to the fresh, unused oils for reference.

2.4 Assessment of the organoleptic quality of French fries and oil baths

Following each frying cycle, the French fries were subjected to organoleptic evaluation in terms of color and taste. Simultaneously, the organoleptic quality of the frying oil was assessed based on its aroma and color. The organoleptic evaluation was conducted by perceiving through the sense organs-taste by using the mouth, aroma by using the nose, and color by observing with the eyes.

2.5 Monitoring of oil quality during repeated frying

All parameters analyzed in this study were assessed according to the protocols in use by the food oil refining company "LaBelle", located in the District of Annaba, Algeria where the work was carried out.

2.5.1 Physical and physicochemical properties

The oil samples taken were analyzed for free fatty acids (FFA) by titrating the FFA with sodium hydroxide (N/2.82) in the presence of ethyl alcohol as a solvent, using phenolphthalein as a color indicator.

The pH measurement was conducted by immersing the two electrodes of the Hanna Instruments HI 99161 pH meter (Hanna Instruments, Woonsocket, RI, USA) into a beaker containing the oil to be analyzed. The pH value was promptly read from the display screen after stabilization of the value.

The relative density was ascertained by submerging the 0900-0950 graduated densimeter in the first test tube containing the oil to be analyzed, while a thermometer was placed in the second test tube. After stabilization of the densimeter, the density reading was recorded in relation to the temperature and subsequently corrected to 20°C.

Oil color was determined using a conventional Lovibond Tintometer Model E operating in transmittance mode, and the results were recorded in Lovibond units. The apparatus is equipped with both standard-color slides and standard-colorless compensation slides. The measure is based on the assessment of oils' color by comparison with *Lovibond* glasses of established color standards. The resultant color is quantified as the cumulative value of the yellow and red slides employed to match the color of the oil sample placed within a specified cell in the Lovibond Tintometer. Results are expressed in the Lovibond unit.

To evaluate the moisture content, the weight loss from a 20 g sample was measured after heating several times in an oven at 105 ± 2°C for 2 hours. The oil was left to cool in a desiccator. This procedure was repeated several times until the discrepancy between two consecutive weight measurements, conducted after one hour of cooling in the desiccator, did not exceed 2 mg.

Table 3. Organoleptic characteristics of Oil-A and Oil-B as frying oils and French fries

Frying number	Color of bath 1/5	Color of bath 1/8	Fries color 1/5	Fries color 1/8	Fries taste 1/5	Fries taste 1/8	Odor of bath 1/5	Odor of bath 1/8
Oil-A								
1	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Odorless	Odorless
2	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Odorless	Odorless
3	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Odorless	Odorless
4	Brown	Clear	Golden	Golden	Agreeable	Agreeable	Odorless	Odorless
5	Brown	Clear	Golden	Golden	Agreeable	Agreeable	Odorless	Odorless
6	Brown (+	Brown	Brown	Golden	Piquant	Agreeable	Disagreeable	Odorless
7	Brown (++	Brown	Brown	Brown	Piquant	Piquant	Disagreeable	Disagreeable
8	Brown (+++	Brown	Brown	Brown	Piquant	Piquant	Disagreeable	Disagreeable
Oil-B								
1	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
2	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
3	Clear	Clear	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
4	Light brown	Clear	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
5	Light brown	Clear	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
6	Brown	Brown	Golden	Golden	Agreeable	Agreeable	Without odor	Without odor
7	Brown	Brown	Brown	Golden	Agreeable	Agreeable	Without odor	Without odor
8	Brown	Brown	Brown	Golden	Agreeable	Agreeable	Disagreeable	Without odor

2.5.2 Chemical indices

The peroxide value (PV) was estimated by titrating the iodine in the sample using a sodium thiosulfate solution (N/100) as a titrating agent. This titration followed the reaction of the peroxides present in the sample with iodine salt (KI). A control test (blank) was conducted concurrently for comparison.

The saponification value (SV) is a measure defined as the number of milligrams of potassium hydroxide needed to saponify 1 g of fat under specific conditions. The SV was evaluated by a method based on the saponification of 2 to 3 g of oil sample by refluxing with a known excess of an alcoholic solution of potassium hydroxide. The mixture was occasionally shaken for 30 min.

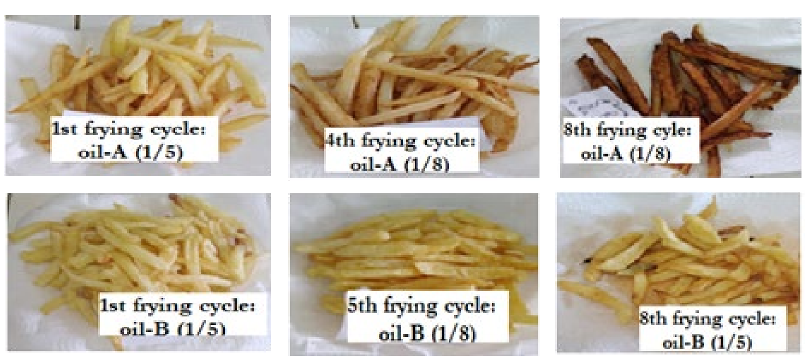


Figure 1. Examples of sample fries obtained from different ratios of frying (1/5 and 1/8); (above: Oil-A; below: Oil-B.)

The amount of alkali required for saponification was determined through titration of the excess potassium hydroxide using standard hydrochloric acid (0.5N) in the presence of phenolphthalein as a color indicator. A blank titration was conducted under identical conditions for comparison.

3 Results and discussion

3.1 Organoleptic evaluation of French fries and oil samples during frying

The repeated frying of cooking oil leads to the deterioration of its sensory quality, evident through changes in color, aroma, and flavor.

3.1.1 French fries and Oil-A

Refined soybean oil is typically characterized by its light-yellow color. During repeated frying, it was observed that the oil from the 1/5 ratio began to darken as early as the 4^{th} frying cycle as compared to the 1/8 ratio which started darkening in the 6^{th} cycle. As for the color of the fry, both rations maintained the golden appearance until the 5^{th} cycle for the 1/5 ratio and the 6^{th} cycle for the 1/8 ratio. A similar trend was noticed in taste, with an unpleasant change taking place around the 5^{th} and 6^{th} frying cycles for the 1/5 and 1/8 ratios, respectively. Finally, the oil baths recovered were odorless until the 5^{th} and 6^{th} frying cycles for the 1/5 and 1/8 ratios, respectively. It can be deduced that the oils maintained their organoleptic properties consistently up until the 4^{th} and 6^{th} frying cycles, corresponding to the respective oil-to-fries ratios of 1/5 and 1/8.

3.1.2 French fries and Oil-B

As for oil-B, its initial color is a light yellow. During the frying tests, this color remained unchanged for the first three and five cycles, respectively, for the 1/5 and 1/8 ratios. Nevertheless, it was observed that the color darkened more rapidly in the 1/5 ratio than in the 1/8 ratio.

When it comes to the color of the fries, it remained clear throughout all frying cycles for the 1/8 ratio. In contrast to the 1/5 ratio where the color started to darken at the 7^{th} frying cycle. However, the taste of the fries remained pleasant for both ratios, even during repeated frying cycles.

It was clear that when small quantities of fresh potatoes were cooked in a large volume of oil, the oil retained its original color and remained odorless for a longer duration. These results clearly indicate that the deterioration of the organoleptic quality is more pronounced when frying is conducted with a ratio of 1/5 (as shown in Table 3 and Figure 1). A significantly larger amount of fresh potatoes introduced into the fryer results in an extended cooking time. Therefore, the prolonged contact of the fries with the high-temperature oil is the primary reason for the deterioration in the quality of the prepared fries. In fact, Ujong et al. [11] stated that the frying process contributes to the leaching of carbon from the French fries into the oil, resulting in the distinctive dark color of fried food. Furthermore, the pigments such as non-volatile decomposition products and carbonyl compounds generated as by-products during deep frying from oxidation and decomposition of fatty acids, contribute greatly to the dark color of the oil [12].

3.2 Physical and physicochemical properties

3.2.1 Acidity and pH

Results indicated that the percentages of FFA, calculated as oleic acid, tend to rise during the frying process. Initially, in its fresh state, the oil-A exhibited an acidity of 0.09%, slightly higher than that of oil-B which was 0.06%. However, this acidity increased by 90% (0.1 to 0.19) and 77.78% (0.09 to 0.16) for the respective 1/5 and 1/8 ratios. Similarly, the acidity of oil-B increased by the same percentage of 62.5% for both ratios (1/5 and 1/8), as shown in Figure 2 A.

The observed increase in acidity in the oil-A baths reflects a greater formation of FFA when compared to the oil-B samples. FFAs originate from oil's triglycerides, which react with water molecules from the French fries during frying, resulting in the formation of both FFA and diacylglycerol [13]. This process highlights the importance of monitoring acidity as an informative measure of oil quality during frying. Nevertheless, according to the company's internal standard, it should be noted that none of the samples, even after the eighth frying cycle, can be deemed inferior in terms of thermal stability based on this parameter, given that all oil samples maintained an acidity level below 0.20% [14].

The results of this present study closely align with those of Mishra and Sharma [12], who noted an acidity of 0.13% and 0.14% in a mixture of rice bran oil and sunflower oil (60:40) during the frying of potato chips, which had initial respective moisture contents of 0.5% and 64.77% after the sixth frying cycle. Similarly, Askın and Kaya [15] observed a significant increase ($p < 0.05$) in the formation of FFA in three different vegetable oils following the frying process (over 5 days). The authors reported FFA percentages of 1.40%, 0.67%, and 0.59% in refined olive oil, refined oleic sunflower oil, and refined linoleic sunflower oil, respectively. These variations were explained by the different linoleic acid contents of the oils. As noted by Maduelosi and Grace [9], a higher percentage of FFA, representing the unesterified fatty acid fractions in the oil, can lead to a loss in oil flavor and potentially result in rancidity.

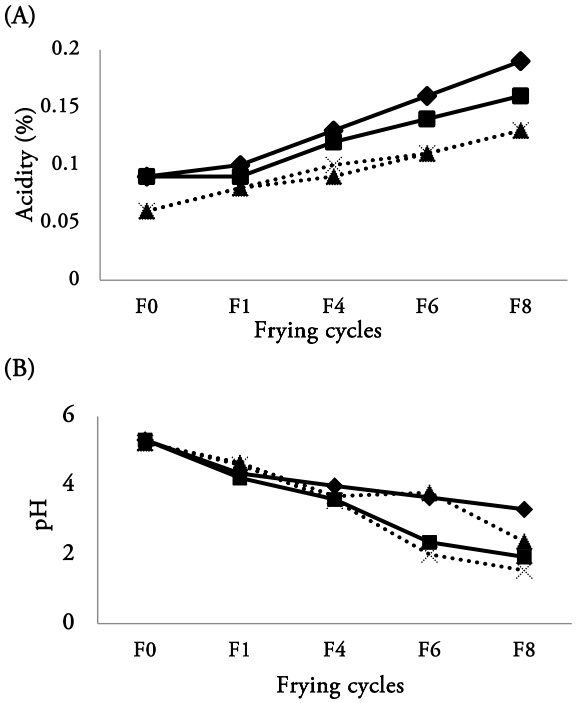


Figure 2. Evolution of the oleic acidity of oils during repeated frying in oil (oil-A and oil-B); (A) acidity; (B) pH ♦: Oil-A (1/5), ■: Oil-A (1/8); ▲: Oil-B (1/5), **x**: Oil-B (1/8)

In Figure 2B, the pH values of both oils during the frying process are depicted. The results indicate a decrease in the pH of fresh oil-A from its initial value of 5.32 to 3.31 and 1.93, representing reduction rates of 37.78% and 63.72% for the 1/5 and 1/8 ratios, respectively. The same trend was observed for oil-B, which had an initial pH of 5.24, which gradually diminished to 2.37 and 1.54, corresponding to reduction rates of 54.96% and 70.61% for the ratios 1/5 and 1/8, respectively. Remarkably, oil-B tended to undergo acidification more rapidly compared to oil-A.

The decrease in pH can be explained by a possible release of FFA throughout hydrolysis during repeated frying, catalyzed by vapors, oxygen, and water from the fried food (in this case, potato). Khan et al. [16] pointed out that the hydrolysis reaction mainly takes place within the oil phase and at the water-oil interface. The rate of hydrolysis is higher for unsaturated fatty acids compared to long-chain saturated fatty acids [14].

3.2.2 Density, color, humidity

In this study, all three parameters (density, color, and humidity) were measured across the eight different oil-frying baths. Density plays a significant role in influencing oil absorption, as it impacts the drainage rate post-frying and the rate of mass transfer during the cooling phase of frying [17].

From the obtained results (Figure 3A), it was observed that there was a consistent increase in density. For the fresh oil-A and oil-B, the initial densities were 0.915 and 0.917, respectively. Those values increased until they settled at density values of 0.918 and 0.919 for the 1/5 and 1/8 ratios, respectively, by the 8^{th} frying cycle oil-A; while oil-B reached the same density of 0.919 for both 1/5 and 1/8 ratios. The current outcomes were close to those obtained by Maduelosi and Grace [9], who noted a density between 0.900 and 0.910 g/mL in their study investigating the impact of repeated frying

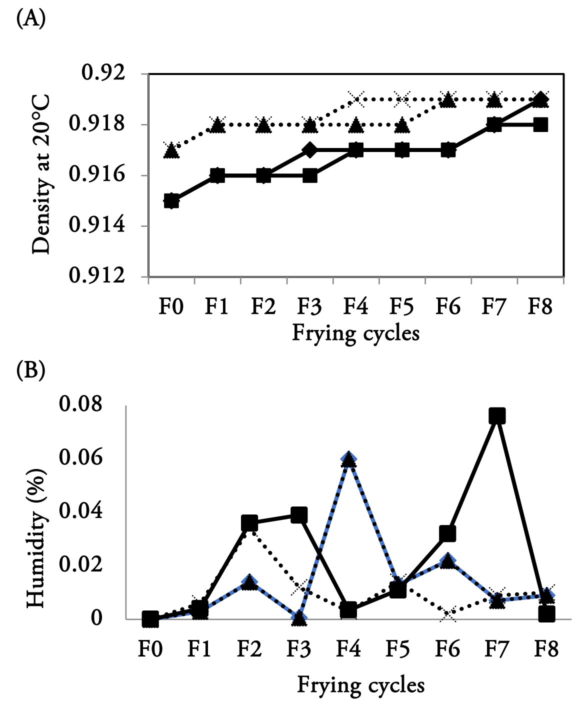


Figure 3. Evolution of density (A) and humidity (B) values of oils during different frying cycles ♦: Oil-A (1/5), ■: Oil-A (1/8); ▲: Oil-B (1/5), **x**: Oil-B (1/8)

on the quality of vegetable oil (specifically, Kings brand) from Nigeria. The increasing densities with frying cycles could be attributed to the formation of higher molecular-weight polar compounds that are often associated with polymerization reactions, taking place within the oils during repeated frying [18].

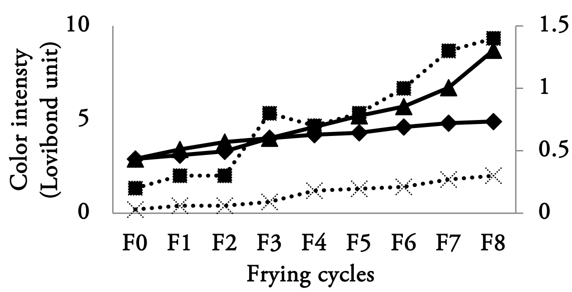
The extent of these increase is contingent on factors such as temperature, the number of frying cycles, and the composition of the samples used, as elucidated by Jurid et al. [19], who described a progressive increase in the density of refined, bleached and deodorized palm olein oil (RBDPO) from the first to the fifth cycle of deep-frying involving potatoes.

Regarding the moisture content, as specified by Dodoo et al. [20], the thermal hydrolysis process in oils is activated through a heat, air, and moisture combination, initiating a thermochemical reaction that leads to the oil's deterioration. The moisture content is an indirect indicator of oil quality and its susceptibility to thermal oxidation.

Fresh samples of both oils were free of moisture. Trace amounts of moisture became detectable starting from the first frying cycle, and the rate consistently rose with each frying cycle. Notably, by the 8th frying sequence, the moisture levels had reached the same value of 0.09% for the 1/5 ratio in both oils. Similar levels were reached around the 8th frying time, with values of 0.09% for the 1/5 ratio in both oils. In the case of the /8 ratio, oil-A had a moisture content of 0.002% while oil-B had a rate of 0.01% (Figure 3B).

The presence of humidity confirms that there is significant water activity (a_w), which fosters the hydrolysis of triglycerides and therefore contributes to the degradation of the oil. The appearance of traces of moisture in the frying baths can be attributed to the natural evaporation of water from the potatoes due to exposure to high temperatures. This phenomenon is observed when water droplets form on the lid of the fryer during frying. Moreover, the increased number of frying cycles intensifies the water evaporation during the thermal hydrolysis of the oil. This result was also confirmed by Warsiki et al. [21], who found that water and evaporated matter content increased when repeatedly fried in palm cooking oil.

(A)



(B)

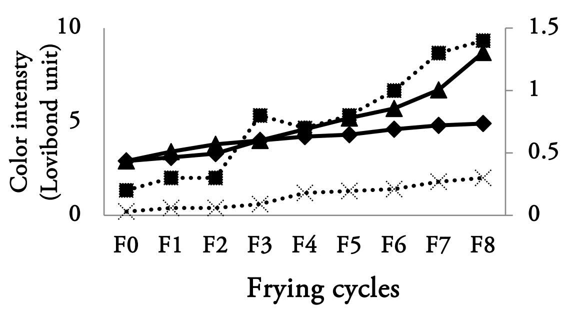


Figure 4. Changes in the color of frying oils during the different frying cycles: oil-A (A) and oil-B (B).

♦ Yellow color (1/5), ▲: Yellow color (1/8), ■ Red color (1/5); **x**: Red color (1/8)

The primary sensory indicator used to assess the quality of oil, particularly when it starts to produce an undesirable fried taste and smell, is its dark color. The obtained results showed that the color, expressed in Lovibond units, increased consistently for both oils across different ratios (Figure 4).

For oil-B, the yellow color began to deviate noticeably from the 3rd frying cycle, exhibiting a rapid increase of about 117.5% and 22.5% for the 1/8 and 1/5 ratios, respectively. A similar trend was observed in the color red. In contrast, oil-A exhibited a more significant change in yellow color; as measured in Lovibond units, starting from the fourth frying cycle for both ratios. This change was particularly pronounced for the 1/5 ratio, where there was a rapid increase from 4.2 to 9.4 Lovibond unit during the last frying cycle. In comparison, the 1/8 ratio showed a rise from 4 to 5.7 Lovibond unit between the 4th and the 8th frying cycles. The same upward pattern was observed for the red color, rising consistently with increasing the number of frying cycles. Indeed, the red color of the oil baths exhibited a significant increase from the 2nd frying cycle, with a more pronounced effect observed for the 1/5 ratio compared to the 1/8 ration.

The changes in the red color of the oils were in line with previous studies, where significant increases in the red color of RBDPO from 3.6 Lovibond unit (fresh oil) to 5.6 Lovibond unit were noted after 5 heating cycles [19]. Additionally, Omara et al. [22] emphasized that changes in the color of oils are a fairly intuitive and quick visual indicator of an oil's tendency to deteriorate. Such color changes in oil, often referred to as oil darkening, are associated with the chemical degradation and development of oxidation products including hydroperoxides, conjugated dienoic acids, ketones, and hydroxides [23].

3.3 Physical and physicochemical properties

Peroxide detection provides the first evidence, offering initial confirmation of fats and oils' rancidity [24]. As elucidated by Jurid et al. [19], the oxidation of double bonds in unsaturated fats principally yields peroxides as its primary oxidation byproducts. High peroxide levels are indicators of the degree of oxidation. Higher peroxide levels serve as reliable indicators for the extent of the oxidation, with higher peroxide contents indicating a greater degree of oil oxidation. This trend of increasing peroxide levels was unequivocally observed in the PV data, as illustrated in Figure 5A.

The initial PV of the fresh oil, up to the fourth frying cycle, consistently adhered to the permissible limits of 15 meq/kg for virgin oils and cold-pressed oils, and 10 meq/kg for other fats and oils as set forth by the Codex Alimentarius Commission [25]. Remarkably, this compliance was observed for all oils tested, except oil-A, which remained within the standards even until the sixth frying cycle, particularly in the case of the 1/8 ratio. However, after the eighth frying cycle, the PVs significantly exceeded these limits. Oil-A exhibited PVs of 19.7 meq/kg (1/5 ratio) and 18.8 meq/kg (1/8 ratio), while oil-B recorded PVs of 21.3 meq/kg (1/5 ratio) and 18.3 meq/kg (1/8 ratio). In the study conducted by Kim et al. [26], a noteworthy and statistically significant rise in the PVs was recorded, surging from an initial value of 0.6 to 6.5 meq/kg throughout the repeated frying (used up to 80 times repeatedly) in the oil extracted from the potato chips that were deep-fat fried in refined coconut oil. Nevertheless, it's important to note that the same analysis pointed out that PVs may not increase continuously during prolonged frying. This is because peroxides, being inherently unstable compounds, tend to undergo decomposition under sustainable high-temperature frying conditions. Therefore, those compounds break down into various other compounds, such as ketones, aldehydes, hydrocarbons, and alcohols, which can influence the overall PV levels in complex ways. The discrepancy observed in the current study diverges from the findings of Kim et al. [26], and this variance could potentially be attributed to differences in the number of frying cycles, which was comparatively lower in our study, and the oil type. The outcomes of the current study revealed higher PVs compared to those documented by Park and Kim [27]. In their research, it was described that the PVs of palm oil increased from 7.08 meq/kg to 15.48 meq/kg after 1-101 deep-fat-frying cycle. Sunflower oil exhibited a similar pattern, with PVs rising from 1.20 to 9.20 meq/kg after the 4th day of frying, but interestingly, it subsequently diminished to 8.80 meq/kg at the fifth day of frying [28]. On the other hand, sesame seed oil experienced an increase from the initial 5.50 to 8.50 meq/kg after five frying cycles of Nigerian potato chips [11]. This observed variation in PVs may be attributed to the presence of double bonds present in fats and oils, which play a fundamental role in autoxidation. As a general rule, oils with higher unsaturated levels tend to oxidize at a faster rate compared to those with lower unsaturated levels [29].

The saponification value (SV) is an indicator reflecting the average molecular weight of the fatty acids present in an oil sample. It exhibits an inverse relationship with the length of the fatty acid chains that esterify glycerol. In this study, there was a notable contrast between the SV of fresh oils and oils subjected to frying, which differed from the trend seen in PV (Figure 5B). Specifically, as the number of frying cycles increased, the SV tended to decrease. In the case of oil-A, the SV passed from 190.77 to 186.56 and 187.56 mg KOH/g for the ratios 1/5 and 1/8, respectively. Similarly, for the oil-B, the SV decreased from 192.17 to 183.76 and 185.16 mg de KOH/g for the same respective ratios. The outcomes achieved were notably higher than those reported by Erum et al. [30] for corn oil and mustard oil at room temperature of 35°C, with values of 153.8 and 125.6 mg KOH/g, respectively. The lower SV obtained in their study suggests a decreased average molecular weight of fatty acids or a lower number of ester bonds. Thus, the elevated SVs recorded in the current work indicate a prevalence of very short-chain (low molecular weight) fatty acids, a consequence of the breakdown of long-chain fatty acids through repeated heating of oils.

3 Conclusion

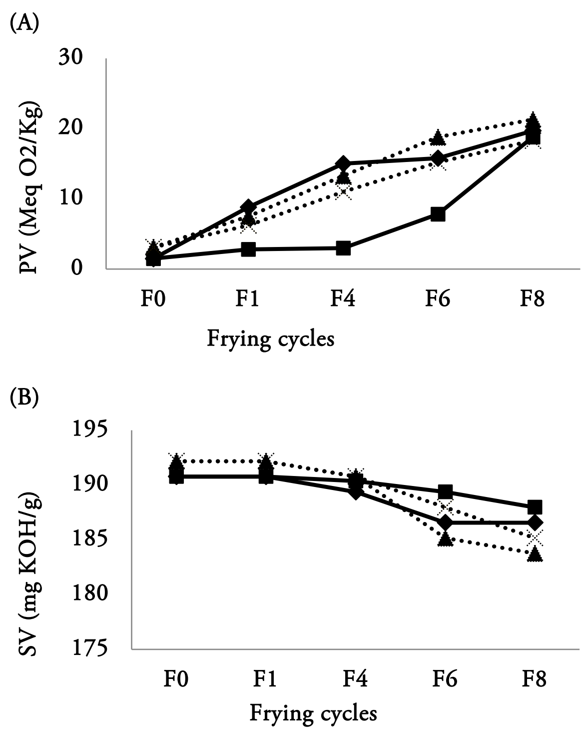


Figure 5. Changes in Peroxide (A) and Saponification (B) values in oil-A and oil-B during repeated frying

◆**:** Oil-A (1/5), ■: Oil-A (1/8), ▲**:** Oil-B (1/5); **x**: Oil-B (1/8)

In view of the obtained results, it is evident that all the assessed parameters follow a consistent trend of either increasing (acidity, density, humidity, color, and PV) or decreasing (pH and SV) values for both tested ratios (1/5 and 1/8). In other words, the oils experience degradation as the number of frying cycles increases, with a notable acceleration in deterioration when a higher ratio of fresh potatoes to oil was used in frying.

Therefore, the degradation was more pronounced when the fries-to-oil ratio was 1/5. Additionally, it was noted that oil-A began deteriorating after the 4th frying cycle, while oil-B showed signs of deterioration starting with the 6th frying cycle. This deterioration of the oil during repeated frying is accompanied by the formation of potentially harmful compounds such as peroxides, hydroperoxides, and trans fatty acids. In light of these, it is advisable to minimize the recurrent and continuous use of fried oils and the frequent consumption of fried foods in order to promote a healthier lifestyle.

Limitations

It would be advantageous to enhance the comprehensiveness of the current study by increasing the sample size to include a wider range of vegetable oil brands. Moreover, extending the number of frying cycles beyond the eighth cycle could provide deeper understandings into the long-term effects of repeated deep-frying on oil quality. Additionally, considering the evaluation of additional quality parameters such as iodine value and polar compounds could enrich the analysis. Nevertheless, the results of this analysis contribute to the findings published in previous studies, thus enriching the data regarding the quality of frying oils marketed and consumed in Algeria.

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