Chemical Characteristic of Repeatedly Frying Oils Used for Frying Falafel

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Abstract:

The study aimed to analyze the chemical changes occurring during the repeated frying of falafel using various vegetable oils, including sunflower oil (SFO), soybean oil (SBO), and corn oil (CO). To assess the safety of these oils throughout repeated frying cycles, a series of laboratory tests were conducted, including the determination of acid value (AV), peroxide value (PV), p-anisidine value (p-AV), total oxidation (Totox), and total polar compounds (TPC). By the end of the fifteenth frying cycle, the acid values of sunflower, soybean, and corn oils increased to 7.17, 2.24, and 3.36 mg KOH/g, respectively, exceeding the maximum permissible limit of 0.6 mg KOH/g. Similarly, the peroxide values of the tested oils surpassed the established threshold of 10 meq/kg, reaching 47.00, 40.33, and 42.67 meq/kg, respectively. The p-anisidine values also showed a significant rise, indicating the formation of harmful secondary oxidation products. Moreover, the Totox values, representing the sum of peroxide and p-anisidine values, exceeded the acceptable limit of 12.3, with sunflower oil showing the highest susceptibility to oxidation. Although total polar compound levels increased during repeated frying cycles, they remained below the recommended maximum limit of 25%. These results confirm the gradual deterioration in oil quality with repeated frying, highlighting the need for continuous monitoring to ensure safety and maintain oil quality. The originality of this study lies in its analysis of the chemical changes occurring in different vegetable frying oils during repeated falafel frying, coupled with a comprehensive assessment of oxidation and quality indicators, providing precise and reliable data on the safety of oils used repeatedly in cooking.

Keywords: *Acid Value; Falafel; Frying; Total Polar Compounds; Vegetable Oils.*

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دراسة الخصائص الكيميائية للزيوت الناتجة عن تكرار عملية القلي في تحضير الفلافل

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ملخص:

هدفت الدراسة إلى تحليل التغيرات الكيميائية التي تحدث أثناء القلي المتكرر للفلافل باستخدام عدة زيوت نباتية مثل زيت عباد الشمس (SFO)، وزيت فول الصويا (SBO)، وزيت الذرة (CO) ولتقييم سلامة هذه الزيوت خلال دورات القلي المتكرر، أُجريت مجموعة من الفحوصات المخبرية شملت تقدير الحموضة الكلية للزيوت (AV)، وقيمة البيروكسيد (PV)، وقيمة الأنسيدين (p–AV)، بالإضافة إلى فحص الأكسدة الإجمالية (Totox)، والمركبات القطبية الإجمالية (TPC). مع نهاية الدورة الخامسة عشرة للقلي المتكرر، لوحظت زيادة في حموضة زيت عباد الشمس وزيت فول الصويا وزيت الذرة لتصل إلى 7.17 و2.24 و3.36 ملغم KOH/كغم على التوالي، متجاوزة الحد الأعلى المسموح به والبالغ 0.6 ملغم KOH/كغم. كما بينت النتائج أن قيمة البيروكسيد للزيوت المذكورة قد تخطت الحدود المقررة (10 ملي مكافئ/كغم)، حيث بلغت على التوالي 47.00 و40.33 و42.67 ملي مكافئ/كغم. وأظهرت نتائج فحص الأنسيدين (p–AV) ارتفاعًا ملحوظًا، مما يشير إلى تكوّن منتجات الأكسدة الثانوية الضارة. كما أن قيم الأكسدة الإجمالية (Totox)، والتي تمثل مجموع قيمة البيروكسيد وقيمة الأنسيدين، قد تجاوزت الحد المقبول البالغ 12.3، وكانت قيم زيت عباد الشمس هي الأعلى، مما يدل على قابليته المرتفعة للتأكسد. ورغم ارتفاع مستويات المركبات القطبية الكلية خلال دورات القلي المتكرر، إلا أنها بقيت أقل من الحد الأعلى الموصى به وهو 25٪. وتؤكد هذه النتائج على التدهور التدريجي في جودة الزيوت مع تكرار القلي، مما يبرز الحاجة إلى وجود رقابة مستمرة لضمان السلامة والمحافظة على جودة الزيت. تكمن أصالة الدراسة في تحليل التغيرات الكيميائية التي تطرأ على زيوت القلي النباتية المختلفة خلال القلي المتكرر للفلافل، مع تقييم شامل لمؤشرات الأكسدة والجودة، مما يوفر بيانات دقيقة وموثوقة حول سلامة الزيوت المستخدمة بشكل متكرر في الطهي.

الكلمات المفتاحية: *قيمة الحموضة؛ الفلافل؛ القلي؛ المركبات القطبية الكلية؛ الزيوت النباتية.*

1. Introduction

Street food is widely consumed in low- and middle-income countries, where it constitutes an integral component of the national economy (Gad-Allah et al., 2023). Falafel pitas are Palestinian classic street food consisting of chickpeas, parsley, garlic, onion, sodium bicarbonate, and salt then served after frying in specific vegetable oils for about 3 min (Al-Degs et al., 2011). It is regarded a highly nourishing product, mostly due to its plant-based components, such proteins, carbohydrates, vitamins, minerals, and dietary fibre (Fikry et al., 2021). Frying oil functions as a medium for heat transfer and simultaneously influences the texture and flavour profile of fried Falafel (Farkas et al., 1996). A wide variety of edible oils, derived from both plant and animal sources, are utilized for frying, depending on regional availability (Pardeshi, 2020). In Palestine, the most important Falafel cooking oils are sunflower oil, soybean oil and corn oil. The oxidative stability of frying oils is inversely related to their degree of unsaturation, as fatty acid composition dictates susceptibility to radical-mediated oxidation and thermal polymerization at elevated temperatures (Bilska & Krzywdzińska-Bartkowiak, 2025). According to Jo et al. (2020), the fatty acid profile of soybean oil is composed of approximately 23% oleic acid (C18:1), 55% linoleic acid (C18:2), and 8% linolenic acid (C18:3). In contrast, corn oil consists of about 28% oleic acid (C18:1), 55% linoleic acid (C18:2), and 13% saturated fatty acids, predominantly palmitic acid (Huda et al., 2024). Sunflower oil, on the other hand, contains around 15% saturated and 85% unsaturated fatty acids, with the latter comprising 14–43% oleic acid (C18:1) and 44–75% linoleic acid (C18:2) (Akkaya, 2018).

However, when these oils are used for cooking or frying at high temperatures, their high linolenic acid content causes oil instability (El-Ghonamy et al., 2015). Frying is the highly complex process where a series of reactions occur simultaneously during the entire process (Oke et al., 2018). However, repeated frying induces a series of oxidative and thermal reactions, resulting in alterations to the physicochemical, nutritional, and sensory properties of the oil (Zahir et al., 2017). In addition, a range of chemical reactions—including hydrogenation, oxidation, polymerization, isomerization, and crystallization—occur during the frying process, leading to the formation of monoacylglycerols, diacylglycerols, free fatty acids, as well as monomers, dimers, and polymers, all of which can alter the appearance, taste, and aroma of fried foods (Abriana et al., 2019; Al-Degs et al., 2011). Research from the Middle East has demonstrated that Falafel quality is adversely affected by prolonged and repeated frying. A Jordanian study found that extended frying time enhances oil absorption, thereby reducing the product's nutritional quality (Abu-Alruz, 2015). Separately, an investigation into Egyptian Falafel production showed that continuous reuse of frying oil accelerates oxidative rancidity, as evidenced by substantial increases in both acid and peroxide values (Ali et al., 2023).

This progressive deterioration of oil quality affects both the frying process and the characteristics of the final product (Dangal et al., 2024). However, repeated use of frying oil promotes smoke and foam formation and induces marked alterations in colour (Abriana et al., 2019). Consequently, the colour and flavour of fried foods become undesirable, while their texture and appearance are less appealing, often accompanied by unpleasant taste and odour (Dangal et al., 2024). In addition, this results in the formation of health-hazardous chemical compounds that can pass into food and diminishes the nutritional value of fried commodities (Ahmad et al., 2021). Excessive consumption of such products can lead to harmful health effects as hypertension, risk of cardiac diseases, impaired kidney and liver functions, and carcinogenic effects (Gad-Allah et al., 2023). Therefore, the purpose of the current study was to investigate the chemical characteristics of oils commonly used for frying Falafel. To the best of our knowledge, this is the first study to systematically evaluate the deterioration of frying oils used in Falafel preparation in Palestine, providing novel insights that enrich the regional understanding of oil stability during high-temperature cooking.

2. Materials and Methods:

1.1 Materials:

Refined sunflower oil, soybean's oil, and corn oil were purchased from a local market in Hebron, Palestine. Falafel dough was also bought from Falafel king restaurant (Hebron, Palestine), 2 hours before frying and stored at 4 °C. All reagents were of analytical grade and were procured from Sigma-Aldrich (St. Louis, MO, USA).

2.1 Methods:

2.1.1 Frying protocol:

A Laboratory-scale frying procedure was undertaken based on (Halim et al., 2016). Three of the most regularly used cooking oils in Palestine—Sunflower oil, Soybean oil, and Corn oil—were evaluated. Samples comprised fresh oil (0 cycle) along with oils exposed to 5, 10, and 15 frying cycles, which were collected for quality analysis. As a food model, one of the most common frying foods in our community (Falafel) was used. Fresh oil was loaded into the 2.5 Litre deep fry pan and heated to 170 ± 5 °C before frying. Each batch of Falafel was fried for about 3 min.

2.1.2 Acid Value (AV)

Acid value was measures according to (Halim et al., 2016). It was determined by liquifying 20 g of oil in 50 mL of a solvent mixture (95 % ethanol: diethyl ether = 1:1) and then using a phenolphthalein indicator to titrate with a 0.1 N NaOH. The titration was performed until pink colour persisting for at least 10 seconds was formed. Acid value is then determined using the following formula (Equation 1).

$$\text{Acid value} = \frac{\text{mL KOH} \times \text{N} \times 56.1}{W} \qquad (1)$$

Where, N is the normality of the KOH solution, W is the sample mass in grams, and the factor 56.1 g/mol is the molecular weight of potassium hydroxide.

2.1.3 Peroxide Value (PV)

The peroxide value (PV) was determined according to the method described by Saoudi et al. (2016). Briefly, a 5 g oil sample was dissolved in 30 mL of a 3:2 (v:v) glacial acetic acid/chloroform mixture in a 250 mL conical flask with stirring. Subsequently, 1 mL of potassium iodide (KI) solution was introduced. The mixture was incubated for one minute in a dark environment with intermittent shaking, followed by the addition of 30 mL of distilled water. For titration, 1 mL of a 5% starch indicator was added, and the solution was titrated with 0.01 N sodium thiosulfate until a colorless endpoint was achieved. The peroxide value of the frying oils was estimated using Equation (2).

$$\text{Peroxide value} = \frac{\text{V} \times \text{N} \times 1000}{W} \qquad (2)$$

Where, V is the volume (mL) of sodium thiosulfate titrant consumed, N is the normality of the titrant, and W is the mass (g) of the analysed sample aliquot.

2.1.4 p-anisidine value (p-AV)

The p-anisidine value was determined using a UV-Vis spectrophotometer (PRIM Light, Germany) according to (Saragih et al., 2023). Briefly, 5 g of oil was dissolved in 25 mL of isooctane, and the initial absorbance (Ab) was measured at 350 nm using an isooctane blank. A 5 mL aliquot of this solution was then reacted with 1 mL of p-anisidine reagent (0.25% w/v in glacial acetic acid). After a 10-minute incubation period, the absorbance of the resulting mixture (As) was measured at 350 nm against the blank. The p-anisidine value of the frying oils was estimated using Equation (3).

$$\mathrm{p-AV} = \frac{25 \times (1.2\mathrm{As} - \mathrm{Ab})}{W} \qquad (3)$$

Where:
As = optical density of the oil solution after reaction with the p-anisidine reagent
Ab = optical density of the oil solution
W = weight of oil sample (g)

2.1.5 Total oxidation value (Totox value)

According to Askın and Kaya (2020), the totox value specifies the overall oxidation of a sample by combining the p-anisidine and peroxide values. In this study, the total oxidation (TOTOX) value was calculated using Equation (4).

$$Totox\ value = (2\ x\ PV) + p - AV \qquad (4)$$

Where, PV is the peroxide value and p-AV is the p-anisidine value.

2.1.6 Total polar compounds (TPC)

Cooking oil tester (Testo 270, Germany) was used to quantity the dielectric constant changes in order to determine the total polar compounds of oils, as stated by Saoudi et al. (2016). The probe of Testo 270 sensor was dipped into the hot oil samples as stated by the instructions of the instrument. This value is expressed as a TPC percentage.

2 Results and Discussion:

2.1 Changes in acid value

Acid value reflect the degree of rancidity as free fatty acids are normally formed during decomposition of triglycerides (Adelagun et al., 2023). The Codex Alimentarius Commission standard stipulates that the maximum acceptable acid value for refined edible oil is 0.6 mg KOH/g oil (Codex Alimentarius Commission, 1999). The acid values (Fig. 1) of the frying oils show a substantial increase with repeated frying cycles, far exceeding both their fresh values and the Codex standard. Initially, the AV of fresh oils—SFO, SBO, and CO—were within the Codex standard limits, aligning 0.60, 0.45, and 0.50 mg KOH/kg, respectively. Though, after just five frying cycles, the AV rose to 5.04, 1.78, and 1.68 mg KOH/kg for SFO, SBO, and CO, respectively, outstanding the permissible threshold. Besides, when compared with SBO and CO, a noteworthy increase in the AV was observed in the SFO after the 5th cycle. This is mostly because sunflower oil contains a lot of unsaturated fatty acids, which are very susceptible to hydrolysis when heat and moisture are present. As a result, a greater quantity of FFAs is produced, raising the acid value (Sadoudi et al., 2014). However, AV increases with increase in frying cycles irrespective of the oil type. The degradation is much more noticeable by the fifteenth cycle, when AV for SFO, SBO, and CO reach 7.17, 2.24, and 3.36 mg KOH/kg, respectively. The results in agreement with the previous findings of Park and Kim (2016), and Lee et al. (2013). This information demonstrates how frequent frying cycles deteriorate oil quality, highlighting the significance of keeping an eye on acid values to make sure oils stay within acceptable and safe ranges for human consumption.

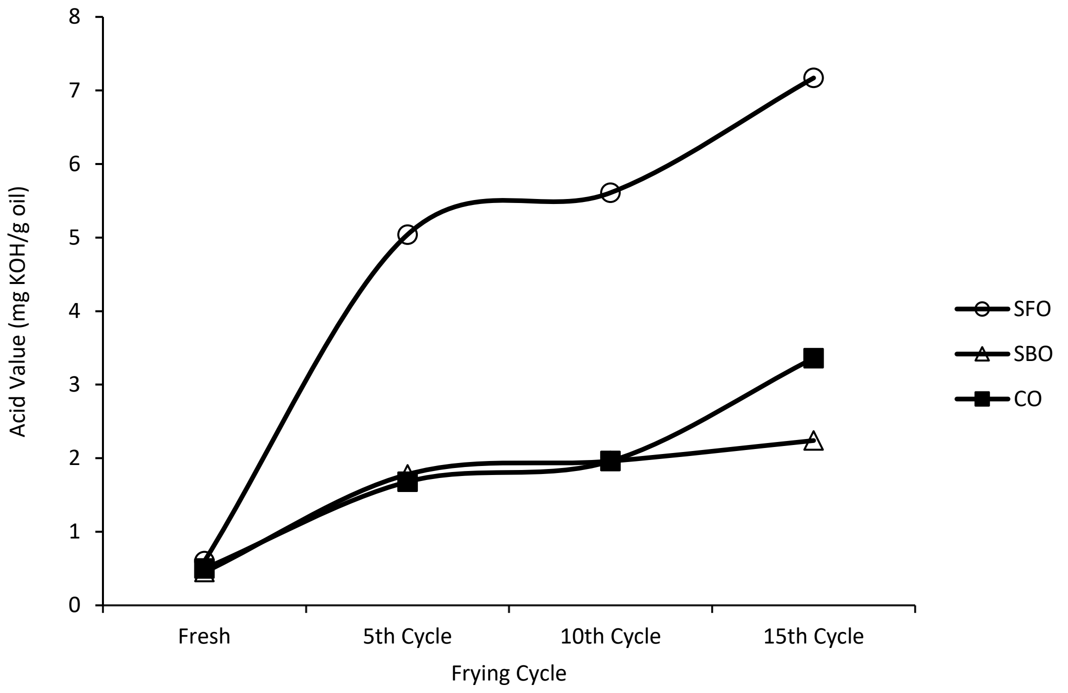

Figure 1:Progressive increase in acid value of sunflower oil (SFO), soybean oil (SBO), and corn oil (CO) with successive frying cycles.

2.2 Changes in peroxide value

The peroxide value is a key indicator of the primary oxidation products in lipids, primarily hydroperoxides. Supposedly, peroxide value is influenced by the storage time, frying temperature, and the reaction between air and oil samples (Jurid et al., 2020). It is advised that high-quality edible oil have peroxide levels of no more than three meq/kg when leaving the processing facility, no more than five meq/kg once the containers are opened, and no more than 10 meq/kg while in use (Habarakada et al., 2021). Consequently, oil that has values greater than 10 meq/kg is not fit for cooking (Codex Alimentarius Commission, 1999). Initially, the peroxide values (Fig.2) for fresh SFO, SBO, and CO are 5.00, 3.00, and 2.00 meq/kg, respectively, suggesting that, the peroxide value of all three oil types were found to be within the standard value of 5 meq/kg. However, as frying progresses, the peroxide values increase steadily, reaching 47.00 meq/kg in SFO, 40.33 meq/kg in SBO, and 42.67 meq/kg in CO after 15 cycles. Peroxide values of the tested oils measured in 5th to 15th cycles had exceeded the standard limit of 10.0 meq/kg. This means that repeated frying using same vegetable oil should be discouraged. The nonconformities from the standard value could possibly be due to the continuous exposure of the oil to light, high temperatures and atmospheric oxygen, which reacts with the oil to form peroxides. Moreover, when the peroxide value is between 30 and 40 meq/kg, a rancid taste is usually perceptible (Godswill et al., 2018). The observed increase in the peroxide value of the three oil brands' is in accordance with the work reported by Habarakada et al. (2021), Idun-Acquah et al. (2016) and Omara et al. (2019). This noticeable trend highlights a basic mechanistic link in which the rise in peroxide value comes before and actively influences the following increase in acid value, as thermally unstable hydroperoxides produced during initial oxidation break down with ongoing heating, leading to the formation of free fatty acids that result in a higher acid value.

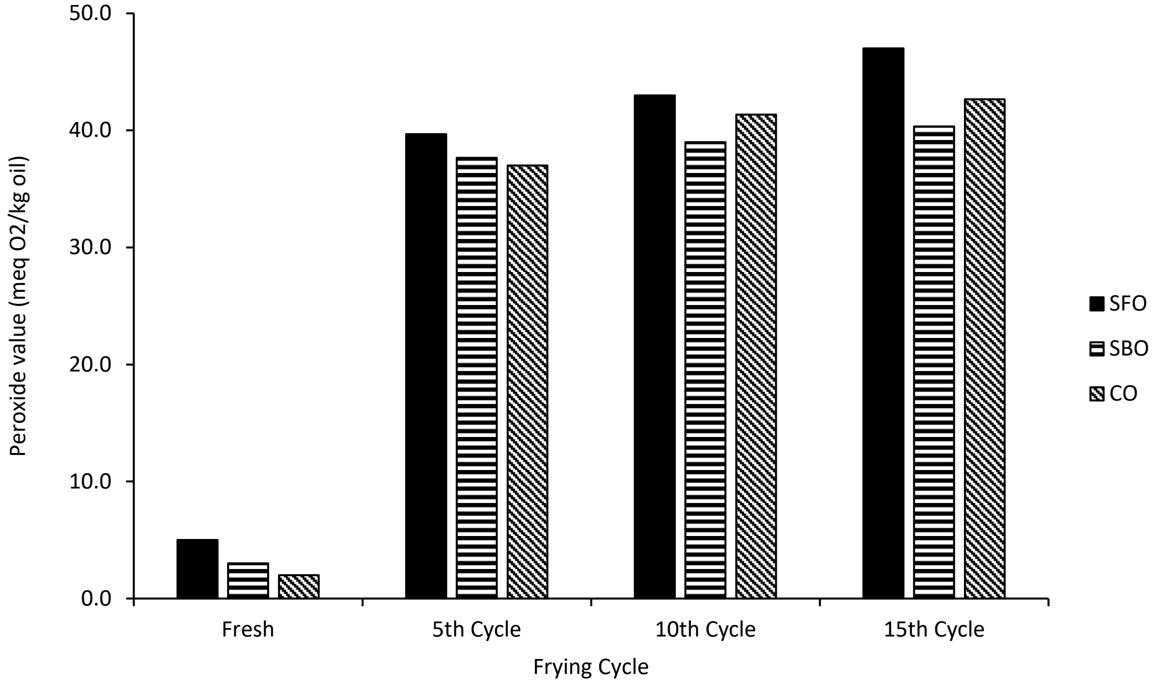

Figure 2: Progressive increase in peroxide value of sunflower oil (SFO), soybean oil (SBO), and corn oil (CO) with successive frying cycles.

3.3 Changes in p-anisidine value

The secondary products caused by lipid oxidation are estimated by the p-anisidine value. A higher p-anisidine value indicates a greater sensitivity to deterioration since it results in a greater quantity of secondary oxidation products (Lee et al., 2021). Figure (3) shows the changes in p-AV of the tested oil samples. The fresh oil p-AV for SFO, SBO, and CO are 5.0, 3.0, and 2.0 respectively. Repetitive frying processes resulted in a substantial increase of p-AV and achieved the maximum at 15^{th} cycle, reaching 47.0, 40.3, and 42.7 for SFO, SBO, and CO respectively. Thus, there was a rise in the p-AV in all oil samples with increasing number of frying cycles. This result is attributed to the degradation of less stable primary oxidation products, specifically hydroperoxides, into secondary oxidative compounds such as aldehydes (Abdulkarim et al., 2007). These results are in agreement with Sebastian et al. (2014) who found that the p-AV ranged from 7.6 to 41.3 for in-use oils withdrawn from the fryer and from 14.2 to 55.8 for discarded oil. Furthermore, the results in consistent with the results reported by Lee et al. (2021), Halim et al. (2016), and Lee et al. (2013). This increase specifies that the frequency of frying accelerates the formation of destructive oxidation by-products, which can be detrimental to the safety and quality of the oils.

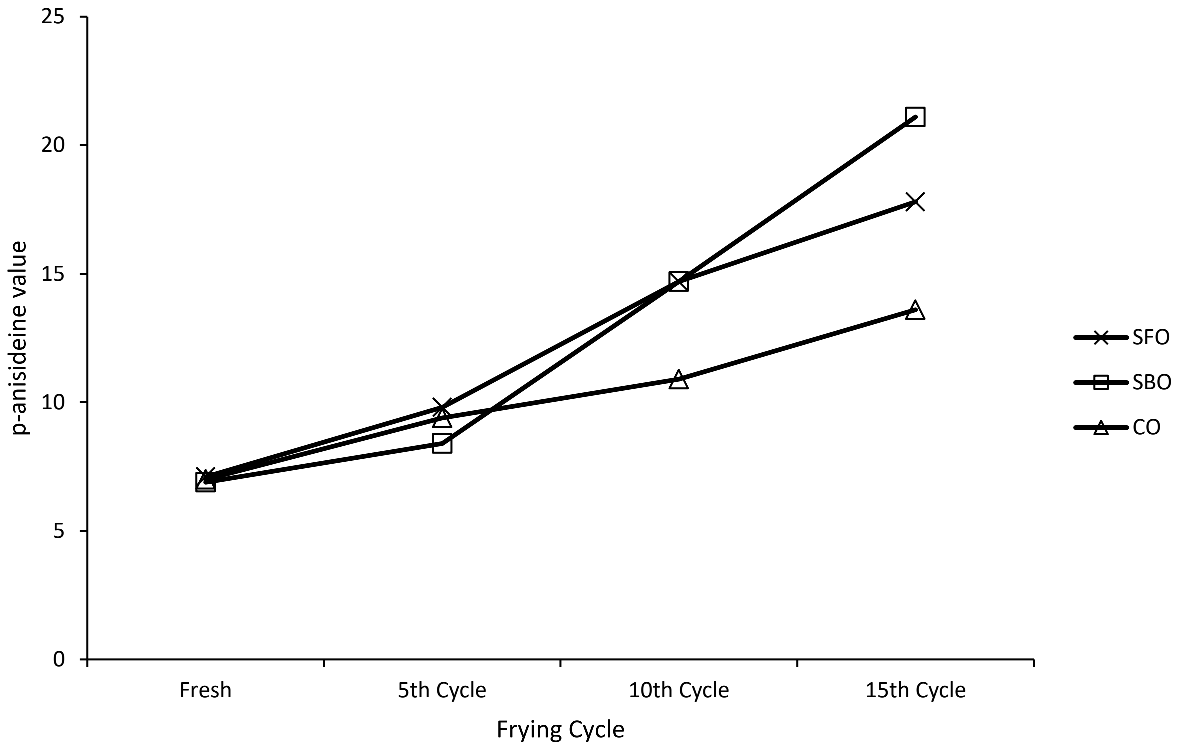

Figure 3: Progressive increase in p-anisidine value of sunflower oil (SFO), soybean oil (SBO), and corn oil (CO) with successive frying cycles.

3.4 Changes in total oxidation value (Totox value)

An indication of total oxidation in fats and oils is provided by the totox value. It is calculated by combining measurements of primary oxidation products (peroxide value) and secondary oxidation products (p-anisidine value). This index is more effective than PV or p-AV alone because fatty acid hydroperoxides are unstable and do not provide a dependable report on the oxidative stability of edible oils. As a whole, edible oils with a totox value below 10 are considered fresh and of high quality. However, for frying oils, the totox value typically ranges between 5.2 to 12.3 (Tavakoli et al., 2019). The results of this analysis are shown in Table 1. After the 15th cycle of frying, the totox value of the frying oils were found to be 111.8, 101.8, and 98.9 for SFO, SBO, and CO respectively. These values far exceed the recommended totox limit, indicating severe oxidation. However, the highest totox values were seen in SFO, thus indicating the lowest SFO stability of frying oil to oxidative rancidity. The higher totox value of SFO shows that the oil is more sensitive to oxidative rancidity than the SBO and CO. This might be due to the high percentages of polyunsaturated fatty acids (linoleic and linolenic acids) compared to SBO and CO. The results in this current study are in agreement with those done in SFO and SBO used to fry frozen Aviko chips by Kondratowicz-Pietruszka and Ostasz (2010). In addition, the present results are in consistent with those reported in a previous studies by Halim et al. (2016), Esfarjani et al. (2019), and Pardeshi (2020).

Table 1: Totox and TPC values of various oils during different frying cycles

Parameter	Oil type	Fresh	5th Cycle	10th Cycle	15th Cycle
	Sunflower oil	17.1	89.1	100.7	111.8
Totox	Soybean oil	12.9	83.7	92.7	101.8
	Corn oil	11.0	83.4	93.6	98.9
	Sunflower oil	6.0	7.5	8.0	10.5
TPC%	Soybean oil	3.5	7.5	8.5	9.5
	Corn oil	8.0	8.5	9.5	13.0

3.5 Changes in total polar compounds

The degree of deterioration in frying oils is revealed by the level of total polar compounds, which are generated by oxidative, thermal, and hydrolytic reactions during the frying process. (Inanc & Maskan, 2014). Based on international food law and policy, the maximum permissible limit for Total Polar Compounds (TPC) in used frying oil is set at 25%. Oils exceeding this threshold are considered waste and are unsuitable for further use in cooking (Paul et al., 1997). The changes in total polar compounds of oil samples are presented in Table 1. From the obtained results, the TPC increased gradually during frying in all samples by increasing frying cycles. TPC for fresh SFO, SBO, and CO are 6.0%, 3.5%, and 8.0% respectively. Repetitive frying processes resulted in a substantial increase of TPC and achieved the maximum at 15th cycle with values of 10.5% for SFO, 9.5% for SBO, and 13% for CO. Regardless of this increase, all values remained below the recommended TPC limit of 25%. The present results are in agreement with those reported in a previous studies by El-Ghonamy et al. (2015), and Pardeshi (2020).

4. Conclusions and Recommendations

In conclusion, this study is the first to systematically evaluate frying oil deterioration in falafel preparation in Palestine, thereby underscoring both its novelty and regional contribution. The repeated use of sunflower, soybean, and corn oils during frying significantly altered their chemical properties, as reflected in rising AV, PV, p-AV, and totox values. With increasing frying cycles, these parameters exceeded acceptable limits, particularly in sunflower oil, indicating accelerated rancidity due to its high unsaturated fatty acid content. Such deterioration not only compromises oil quality but also poses potential health risks, including gastrointestinal disorders and related acute illnesses. These findings highlight the necessity of routine monitoring to ensure oil safety and preserve quality during repeated frying. To strengthen the practical implications, vendors should restrict frying to fewer than five cycles, select oils with greater oxidative stability, and implement systematic monitoring of oil quality, while policymakers are encouraged to establish clear regulatory standards and provide structured training programs for food vendors to promote safe frying practices and protect consumer health.

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