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Research Article

Chemical, Physical, and Technological Characteristics of Palm Olein and Canola Oil Blends

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Because of the limited technical properties of their native forms, oils and fats are frequently blended to achieve the desired textural and oxidative properties. In this study, canola and palm oil blends were prepared in nine different proportions: B1 (90 : 10), B2 (80 : 20), B3 (70 : 30), B4 (60 : 40), B5 (50 : 50), B6 (40 : 60), B7 (30 : 70), B8 (20 : 80), and B9 (10 : 90). Pure palm oil (PO) and canola oil (CO) were used as the controls. All blends were assessed for physicochemical properties, fatty acid composition, heat treatment, and polymer content. The results indicated negative cold tests only for B1 and B2 blends with 10 and 20% PO, respectively. Iodine value decreased with increasing palm oil concentration and was lowest (62.03 ± 0.526) for blend B9, i.e., 90% PO. The fatty acid profile indicated more saturated fatty acids and a higher percentage of oleic acid in PO than in CO. The fatty acid profile values of blends B1–B9 were between those of the pure PO and CO. Linoleic and linolenic acids were more in blends B1–B9 than those in pure PO. The polymer content of PO (7.17%) was found to be lower than that of CO (10.32%) after 60 h of heating at 180°C. In addition, biologically active substances (BASs), which could be formed during the frying process, were tested by measuring the inhibition zone of *E. coli* growth. PO retarded BAS formation. The blended palm or canola oils resulted in better stability and increased organoleptic characteristics and hence can be suitable as economical and healthy alternatives to pure palm or canola oil.

1. Introduction

Oils and fats are used for food preparation, frying, and cooking. Owing to their distinct chemical and physical characteristics, the majority of vegetable oils have limited technical applications in their native forms [1, 2]. To improve their commercial applicability, vegetable oils are frequently transformed using four main techniques: hydrogenation, interesterification, fractionation, and mixing [3–5]. One of the simplest ways to produce new and unique products with specific textural and oxidative properties is to combine vegetable fats/oils with diverse properties [6–8]. Different oils and fats have different physical and chemical properties. One unmixed vegetable oil can have weak oxidative stability and low physical, chemical, and nutritional qualities; therefore, different oils, such as canola or palm oil [9, 10], are blended to accomplish the desired goals and satisfy business demands [11]. A new oil with better

functional capabilities and application in the completed product was produced by blending multiple fats and oils with distinct properties [12, 13]. According to previous studies, combining these oils with higher and more unsaturated oils results in a clearer mixture that is more stable during storage [14, 15]. The food sector can use this blend in a wider range of situations. When fats and oils are blended, the triacylglycerol profile changes, which affects the physical characteristics of the oil, including its cloud point, solid fat content, sensory quality, smoke point, density, and viscosity [14, 16–19]. Color is one of the key characteristics that affect consumer acceptability. Pure oils have distinct colors, some of which can have unfavorable consequences on their acceptance owing to their strengths or weaknesses. Their color can be moderated by blending with the right oil [20–22]. Blending can also result in a decrease in viscosity during deep-fat frying [23, 24]. In general, combining oils with various characteristics can result in an oil that is stable at frying temperatures without hydrogenation or the production of trans fatty acids [4, 6, 16]. Palm oil as an excellent cooking oil and vegetable shortening has become one of the leading vegetable oils consumed worldwide because of its good quality and properties [25–30]. Canola oil is one of the major vegetable oils consumed in Western countries since it constitutes over 70.5% of the total oil production [31, 32]. Canola oils have considerable linolenic acid levels but low oxidative stability; however, palm oil has high oxidative stability with low quantities of essential fatty acids and significant concentrations of saturated fatty acids [33, 34]. Therefore, this work was carried out to prepare different blends of canola oil with palm olein and study their physicochemical properties, fatty acid profile, stability, and the effect of blending canola oil with palm olein on the formation of polymer compounds during the heating process at 180°C for 60 h. This study also evaluated the flavour performance of canola oil and its blends with palm olein during the intermittent frying of potato chips.

2. Materials and Methods

2.1. Materials. Refined palm oil (PO) was obtained from Egypt Foods Group for the food industry. Refined canola oil (CO) was purchased from the Tanta Oil and Soap Company, Egypt. Potatoes (*Solanum tuberosum*) were purchased from a local market, washed thoroughly before air drying, and stored in the dark for further use. E. Coli (H10.7) strain was procured from Microbiology Prodcuts Limited Co., Michigan, USA USA.

2.2. Methods

2.2.1. Experimental Design. Laboratory experiments were performed at the Department of Food Science and Technology, Faculty of Agriculture, Menoufia University, Egypt. This study was designed to evaluate the physicochemical properties, fatty acid composition, heat treatment, oxidative stability, and toxicity of palm oil and canola oil blends in different proportions. Canola and palm oils were blended in nine different proportions: B1 (90 : 10), B2 (80 : 20), B3 (70 : 30), B4 (60 : 40), B5 (50 : 50), B6 (40 : 60), B7 (30 : 70), B8 (20 : 80), and B9 (10 : 90). Pure palm oil (PO) and canola oil (CO) were used as the controls. All experiments were conducted in triplicate, and the results are expressed as mean ± standard deviation.

2.2.2. Physiochemical Properties of Blended Oils

(1) Cold Tests. This method measures the resistance of the oil to crystallization and is commonly used as an index of the winterization and stearin removal processes. A clean and dry corked bottle containing 20–25 g of filtered oil was placed in an ice bath at 7°C. The samples were examined for clarity after 5.5 hours. Oils that are transparent in appearance are more stable when stored at low temperatures (AOCS Official Method Cc 11–53).

(2) Color Measurement. A Lovibond tintometer (Model E) was used to measure the color using a 5.25-inch cell according to the A.O.C. method [35].

(3) Specific Gravity. 50 ml pycnometer bottle thoroughly washed with water followed by petroleum ether was dried and weighed. The bottles were filled with water, weighed, and dried. The same procedure was repeated except that oil was used instead of water. The measurement was performed at 25°C and calculated as follows (AOCS Official Method Cc 10a-25):

$$\text{specific gravity} = \left(\frac{\text{Wt. of } X \text{ ml of oil}}{\text{Wt. of } X \text{ ml of water}}\right). \quad (1)$$

(4) Refractive Index. The Refractive index of the oil samples was measured using an Abbé refractometer (Carl Zeziz JENA, GDR) at 25°C, according to AOAC (2000).

(5) Viscosity. The relative flow time at 60°C was determined using the Ostwald viscometer according to the method in [36]. Changes in the viscosity of the oils during frying were determined using a Brookfield Viscometer RVDV-1+C/P (Cone/Plate Viscometer, CP-41) connected to a water bath (Brookfield TC500). Viscosity was measured at 25 ∗ 0.01°C according to the method described in [37, 38].

(6) Iodine Value. The combined oil was weighed into a 500 ml conical flask with a glass stopper at a weight of approximately 0.130 g. A blank flask was made devoid of oil. The sample and blank flasks each received 15 ml of a 1 : 1 mixture of cyclohexane and acetic acid solution. The two flasks were then filled with 25 ml of Wij's solution, sealed with a glass stopper, and shaken thoroughly. One hour was spent with the flasks in the dark. Then, to release iodine from the unreacted iodine monochloride, 20 ml of potassium iodide and 150 ml of distilled water were added. Before adding 1-2 ml of starch solution as an indicator and continuing the titration, all mixtures were finally titrated

with sodium thiosulfate solution until the yellow color almost completely vanished. When the blue color of the starch solution disappeared completely, the process was complete.

(7) Peroxide Value. A total of 5 g of combined oil was weighed and placed in a conical flask (250 ml). A blank flask was made devoid of oil. The flasks were filled with 30 ml of acetic acid/chloroform mixed solvent and left for one minute while occasionally swirling. Thirty milliliters of distilled water were then added. Sodium thiosulfate (0.1 N) was added to the mixture and titrated until a brown color was achieved. Next, 0.5 ml of a 1% starch solution was added, and the titration was repeated until the blue/gray color disappeared. To guarantee that all iodine is released from the chloroform layer during titration, the mixture must be forcefully agitated [39–41].

(8) TOTOX Value. The total oxidation (TOTOX) value was calculated as 2 PV + AV [42], where PV = peroxide value and AV = anisidine value.

(9) Anisidine Value. Anisidine values were determined in triplicate for each sample, based on the A.O.C.S. Official Method (1992).

2.2.3. Fatty Acid Composition of Blended Oils. Fatty acid methyl esters were prepared according to [43]. The prepared fatty acid methyl esters were analyzed using gas chromatography (PYE Unicam; Model 4550) equipped with a flame ionization detector. The fractionation of fatty acid methyl esters was conducted using a coiled glass column (1.6 m × 4 mm) packed with chromosorb C and coated with 10% polyethylene glycol adipate (PEGA). The H2 , N2 and airflow rates were 33.30, 33.30 and 330 mL/min, respectively, and temperatures in the oven were 180°C and 300°C, respectively. Peak areas and retention times were measured using a Spectra-Physics 4719 integrator.

2.2.4. Heat Treatment and Effect of Heat Treatment on Physiochemical Properties of Blended Oils. Canola oil, single-fractionated palm olein, and its blends were subjected to a continuous heating process at 180 ± 5°C using an electrical fryer of three kilograms capacity for 60 h. A total (250 g) of treated oil was collected periodically after 10, 20, 30, 40, 50, and 60 h for analysis [44].

(1) Induction Period. The induction periods of blended oil samples were determined at 100°C using the Rancimat method, and the test samples were prepared exactly as described for the Schaal oven method. A 679 rancimat (Metrohm, Herisson, Switzerland) was used. 5 gm oil from each test sample was loaded into the reaction vessel cylinder. Three different samples and a control sample were used for each batch. The air supply was maintained at 20 ml/min, and the heating temperature was maintained at 110°C throughout the experiment, as described in [45].

(2) Frying Performance of Blended Oils. The method in [46] was used to determine the frying performance of blended oils (percentage polymer content).

(3) Effect of Repeated Frying on Flavour Scores of Potato Chips Fried in Canola Oil Blends with Palm Olein (PO). Canola oil and its blends were used, i.e., 20% and 30% single-fractionated palm olein, in frying experiments. One kilogram of each oil was heated in an electrical deep fryer at 180°C ± 5. Then, hundred grams of previously prepared potato chips were deep-fried at one hourly interval; the residence time for the frying process was approximately 5 min. The temperature of the oil before each frying process was 180°C, but during the actual frying process, it ranged from 120°C to 130°C. Canola oil and palm olein blend samples were used in intermittent frying procedures, that is, 4 h daily (four batches) for five days. The residual oil was allowed to cool overnight at room temperature before using the following day. Approximately 25 g of oil samples was withdrawn at the end of every four-hour frying process and kept in brown bottles in the refrigerator until analysis. However, fried chips were sampled at the start of the frying operations on the first day (four batches) and repeated daily for five days. Excess oil from the chips was drained, and the chips were allowed to cool. For each batch, 50 g samples of potato chips were packed in sealed polyethylene pouches and kept in a refrigerator until organoleptic evaluation. Four samples (per day) were taken at five-day intervals for sensory evaluation after being salted. The potato chip samples were tested for flavour by ten semi-trained panel members. A 5-point hedonic scale was used for scoring. Higher values are denoted as better quality, according to the procedure in [47, 48].

2.2.5. Determination of Polymer Content. The method described in [49] was used to determine the polymer content.

2.2.6. Toxicity of the Abused Frying Oils. The formation of biologically active substances was determined by the production of a clear zone around the oil-treated discs of the filter paper. Growth inhibition zones were estimated using a graduated ruler micrometer according to previous studies [47, 48].

2.2.7. Statistical Analysis. Data comparison was performed using one-way analysis of variance (ANOVA), Tukey's test, and independent sample *t*-test for all data interpretation at $p < 0.05$. Data for multiple variable comparisons were analyzed using one-way analysis of variance (ANOVA) [50–53].

3. Results and Discussion

3.1. Effect of Blending Canola Oil with Palm Olein on Its Cold Test as well as Physical and Chemical Properties. Blending does not always have negative consequences for a person's health. One of the simplest ways to produce new, special products with the desired textural, oxidative, and nutritional values that lead to better industrial applications and improved functional characteristics is to combine vegetable fats/oils with diverse compositions and properties [54]. The results of the cold tests are presented in Table 1. As indicated in the table, with an increase in palm oil concentration from 30% to 90%, the cold test was positive for all the blends; however, blends containing 10% and 20% palm oil showed negative cold tests; similar results were reported in [14].

Iodine value decreased with an increase in palm oil concentration and was lowest (62.03 ± 0.526) for blend B9 (90% PO + 10% CO). This can be ascribed to the fact that palm oil contains more saturated fatty acids, leading to higher melting points, which ultimately promotes clouding. This can also be explained by the fact that lower iodine values of blended oils lead to a decrease in the resistance of blended oils toward the cold test [55, 56]. The color value of fresh canola oil ($p < 0.05$)was much higher (4.4), than palm olein (2.3). This was probably due to the presence of more carotenoid pigments in the fresh canola oil (Figures 1(a)–1(e)).

These results are in agreement with those of the authors of [20, 57] who reported that fresh palm olein is deeper in color than canola oil. According to [20, 57, 58], color can be moderated by blending the appropriate oils and fats. Moreover, oil blending may alter odor characteristics [59]. However, blending canola oil with palm olein improved the color of the blended oil. The palm olein refractive index was somewhat lower than that of CO (1.4634 and 1.4705, respectively; Figure1(c)) due to the abundance of saturated fatty acid of PO to CO. Generally, the obtained results of the specific gravity refractive index and flow time percentage are in good agreement with those found in [60–63].

3.2. Chemical Properties of Canola Oil, Palm Olein, and Their Blends. Blending canola oil with palm olein improves its oxidative stability because blending inhibits the formation of primary and secondary oxidation products [64]. Canola oil is more unsaturated, with an iodine value of 109, which is higher than that of single-fractionated palm olein with an iodine value of 57 (Figures 2(a)–2(d)). Blending canola oil with palm olein resulted in a change in iodine value according to the blend percentage.

Blending canola oil with palm olein improved its quality during hydrolysis and oxidative processes, as indicated by the tested parameters. The peroxide value of fresh refined canola oil was 1.09, which was approximately two-fold that of fresh palm olein (0.53). The results also indicated that the TOTOX value of canola oil was two-fold higher than that of palm olein, which was 4.68 and 2.18, respectively. The TOTOX value of the blended oil decreased regularly with an increasing percentage of palm olein [65, 66].

Table 1: Cold test at 0°C for 5.5 h of canola oil, palm olein, and their blends (w/w).

Blends	Iodine value	Cold test
CO	109.01 ± 0.01^{a}	Negative
PO	57.10 ± 0.12^{j}	Positive
B1	102.90 ± 0.14^{b}	Negative
B2	97.9 ± 0.14^{c}	Negative
B3	92.71 ± 0.12^{d}	Positive
B4	85.05 ± 0.01^{e}	Positive
B5	82.51 ± 0.35^{f}	Positive
B6	76.42 ± 0.28^{g}	Positive
B7	71.11 ± 0.34^{h}	Positive
B8	66.03 ± 0.62^{i}	Positive
B9	62.03 ± 0.53^{q}	Positive

Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same column, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

3.3. Effect of Blending Canola Oil with Palm Olein on Its Fatty Acid Composition. The benefits of several oils can be combined in a single mix with a balanced ratio of various fatty acids while maintaining their original flavour and nutritional value. Moreover, it adds beneficial antioxidants and bioactive lipids to the final blend [65, 67]. Canola oil contained 25% saturated fatty acids (SFAs), which consisted of six fatty acids, and palmitic acid was the main SFA (19.79%), followed by stearic acid (4.04%). While unsaturated fatty acids (UFAs) were 75%, linoleic acid was the predominant UFA (49.98%) in canola oil, followed by oleic acid (23.6%). Also, palm olein contained 41.8% SFA and consisted of 6 fatty acids. Palmitic acid was the major SFA amounting to 34.3%, and oleic acid was the major UFA (43.96%), followed by linoleic acid (14.13%). These results agree with those obtained in [17, 68]. Blending canola oil with palm olein led to a gradual increase in total SFA with an increasing palm olein ratio, and the same trend was also observed for palmitic acid. On the other hand, the UFA gradually decreased with an increasing percentage of palm olein added to canola oil. The same phenomena were also observed for linoleic acid, while oleic acid showed a notable gradual increase with increasing proportions of palm olein added to canola oil (Table 2). The fatty acid compositions of the investigated oils and their blends are listed in Table 2. These results indicate that there is a marked difference in the fatty acid composition of the oils used to prepare the oil blends. Palmitic acid was found the highest in palm olein (34.3%), followed by canola oil (19.79%), respectively. Palm olein was the highest source of oleic acid (43.962%), whereas canola oil was the richest source of linoleic acid (49.988%). The unsaturated fatty acids represented 74.992 and 58.162% of the total fatty acids of canola and palm olein oils, respectively. However, palm olein oil was the highest source of total saturated fatty acids (41.83%), followed by canola oil (25.07%), respectively. Oils such as palm olein, rich in saturated fatty acids, are more stable to oxidative and hydrolytic breakdown and less prone to polymerization during heating; however, oils rich in linolenic acid are particularly susceptible to these undesirable changes upon use in the frying process [69, 70]. However, Valantina and Neelamegam [65] found that blending sunflower oil with

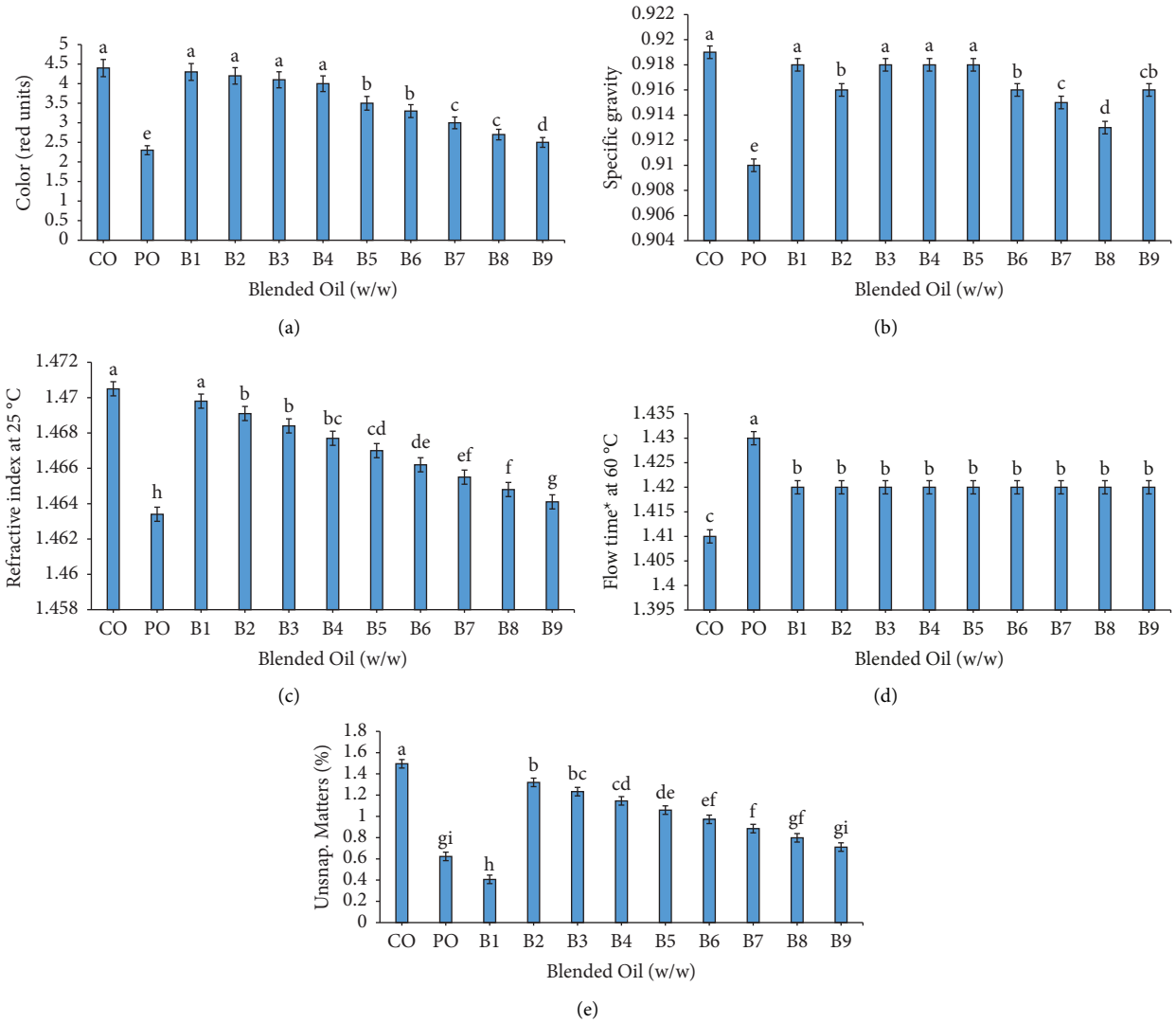

Figure 1: (a–e) Physical properties of canola oil, palm olein, and their blends (w/w). Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

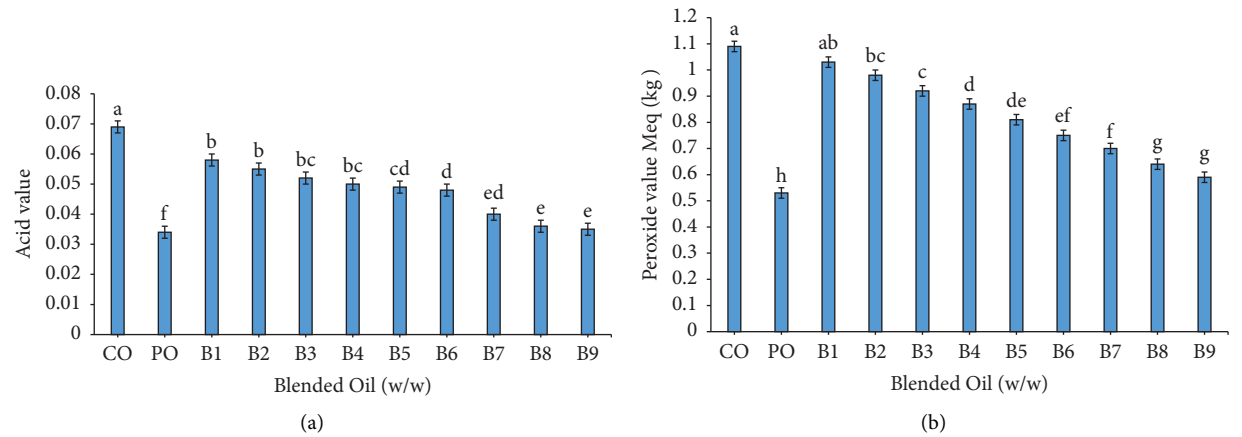

Figure 2: Continued.

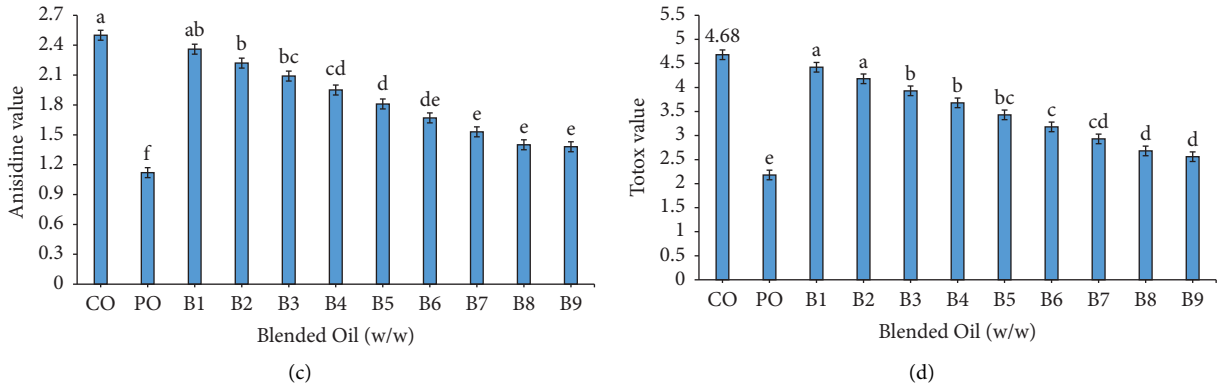

FIGURE 2: (a–d) Chemical properties of blended canola oil with palm olein. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

palm olein at a percentage ranging from 30 to 50% of palm olein improves the frying stability. In addition, Sharma et al. [71] found that blending palm olein with cottonseed oil proved to be useful from both technical and nutritional points of view. These findings indicate that oil blends, B1–B9, could be used as frying as well as cooking and salad oils.

3.4. Effect of Heating on Physical Properties of Different Oil Blends (Induction Period, Refractive Index, Flow Time, and Color). It is evident from the data in Figure 3 that the induction period of palm olein at 100°C was much higher than that of canola oil, as the induction periods at 100°C were 34.2 and 7.35 h for palm oil and canola oil, respectively. This indicates that the stability of palm olein is approximately five times that of canola oil. The increase in the induction period of palm olein was due to the high content of both tocopherols and tocotrienols. These natural antioxidants provide palm olein and its blends with the special and unique advantages of being stable and nutritious. This high level of tocotrienols (150 mg/100 g) and tocopherols (18 mg/100 g) encouraged a trend of decreasing the level of industrial antioxidants, which have some nutritional problems [72–75]. Consequently, blending canola oil with palm olein improves its oxidative stability. These results are in good agreement with those obtained in [64, 76, 77].

Palm olein is usually used as a frying medium; it is of primary importance to study the effect of blending canola oil with palm olein on its quality aspects during successive heating at 180°C up to 60 h. The results in Figure 4 show that with increasing concentration of palm oil, the induction period increased throughout all the blended samples, indicating that the change in the refractive index of canola oil was two times higher than that of palm olein. This could be attributed to the high content of natural antioxidants in palm olein compared to canola oil, and these antioxidants underwent remarkable decrements during the heating of canola oil compared to palm olein. A similar observation was reported in [64]. Therefore, blending canola oil with palm olein prevented the deterioration of its characteristics during heating.

It is clear from the results illustrated in Figure 5 that the increase in the flow rate of the heated palm olein was less than that of canola oil under the same experimental conditions.

This emphasizes that palm olein is a more stable oil than canola oil. The lowest flow time was observed for B8 at any heating time, followed by B7. This could be attributed to the lower content of unsaturated fatty acids compared to that in canola oil. In addition, these results indicate that B8 oil could be considered more suitable for frying than other blends. Generally, the obtained results were in good agreement with those obtained in [78]. Figure 6 shows that blending canola oil with palm olein induced a lower color development rate in blended oil than in canola oil during the heating process. Blends, B8 and B7, could be considered the most promising oils for frying purposes. These results are consistent with those reported in [78–80].

3.5. Effect of Heating on Chemical Properties of Different Oil Blends (Acid Value, Anisidine Value, TOTOX Value, and Iodine Value). The results in Figure 7 demonstrate the high stability of palm olein compared to that of canola oil. As expected from Figure 7, blending canola oil with palm olein improved the acid value after 66 h of heating. The acid values of all blended oils did not reach the endpoint. However, B8 and B7 are used as frying oils. An increase in acid value due to successive heating or frying of oil was also observed [24, 80, 81].

It is evident from Figure 8 that heating the fresh canola oil to 180°C increased its peroxide value more than palm olein. It could also be observed that the peroxide value gradually increased after being heated for 20 h followed by a sharp decrease after 60 heating hours. These results indicate that peroxides are formed during the first 30 h of heating, after which they usually decompose or polymerize. A similar observation was reported in [24, 81, 82].

Anisidine values for canola oil were the highest among palm olein and blended oils (Figure 9). These results indicate that palm olein performed better in the primary oxidation state (peroxide value) and secondary oxidation state (anisidine value). These results are in agreement with those

Table 2: Fatty acid composition of blended canola olein with palm olein (% w/w).

Fatty acid	Canola olein (CO)	Palm olein (PO)	90% CO 10% PO	80% CO 20% PO	70% CO 30% PO	60% CO 40% PO	50% CO 50% PO	40% CO 60% PO	30% CO 70% PO	20% CO 80% PO	10% CO 90% PO
Lauric C 12 : 0	0.0312 ± 0.011^{A}	0.037 ± 0.012^{A}	0.031 ± 0.015^{A}	0.032 ± 0.014^{A}	0.033 ± 0.017^{A}	0.034 ± 0.015^{A}	0.034 ± 0.012^{A}	0.033 ± 0.012^{A}	0.032 ± 0.014^{A}	0.032 ± 0.012^{A}	0.030 ± 0.012^{A}
Myristic C 14 : 0	0.769 ± 0.014^{CD}	1.53 ± 0.011^{A}	0.843 ± 0.014^{B}	0.922 ± 0.014^{BC}	1.02 ± 0.019^{BC}	1.083 ± 0.012^{AB}	1.107 ± 0.016^{AB}	1.190 ± 0.012^{AB}	1.273 ± 0.015^{AB}	1.325 ± 0.012^{AB}	1.487 ± 0.011^{A}
Myristoleic C 14 : 1	0.043 ± 0.012^{A}	0.006 ± 0.010^{B}	0.040 ± 0.019^{A}	0.048 ± 0.012^{A}	0.038 ± 0.015^{A}	0.031 ± 0.011^{A}	0.024 ± 0.014^{A}	0.018 ± 0.012^{A}	0.009 ± 0.016^{B}	0.010 ± 0.012^{AB}	0.009 ± 0.010^{B}
Palmitic C 16 : 0	19.79 ± 0.012^{E}	34.3 ± 0.014^{A}	21.2 ± 0.014^{DE}	22.69 ± 0.012^{D}	24.32 ± 0.014^{CD}	25.70 ± 0.012^{C}	27.13 ± 0.016^{CD}	29.114 ± 0.012^{BC}	29.95 ± 0.018^{BC}	31.371 ± 0.012^{AB}	32.942 ± 0.012^{A}
Palmitoleic C 16 : 1	0.848 ± 0.015^{AB}	0.296 ± 0.019^{EF}	0.792 ± 0.014^{BC}	0.734 ± 0.010^{BC}	0.698 ± 0.019^{CD}	0.668 ± 0.125^{CD}	0.972 ± 0.014^{A}	0.989 ± 0.012^{A}	0.467 ± 0.016^{E}	0.327 ± 0.012^{E}	0.351 ± 0.012^{E}
Heptadecanoic C 17 : 0	0.113 ± 0.010^{A}	0.127 ± 0.014^{A}	0.114 ± 0.015^{A}	0.108 ± 0.014^{A}	0.113 ± 0.012^{A}	0.189 ± 0.012^{A}	0.120 ± 0.011^{A}	0.125 ± 0.012^{A}	0.123 ± 0.014^{A}	0.124 ± 0.012^{A}	0.125 ± 0.014^{A}
Heptadecanoic C 17 : 1	0.21 ± 0.008^{A}	0.038 ± 0.014^{D}	0.198 ± 0.014^{A}	0.164 ± 0.018^{B}	0.155 ± 0.017^{B}	0.148 ± 0.019^{B}	0.125 ± 0.013^{C}	0.114 ± 0.012^{C}	0.107 ± 0.017^{C}	0.085 ± 0.012^{D}	0.055 ± 0.013^{D}
Stearic C 18 : 0	4.02 ± 0.018^{B}	5.47 ± 0.015^{A}	4.165 ± 0.018^{B}	4.430 ± 0.010^{B}	4.45 ± 0.019^{B}	4.270 ± 0.018^{B}	4.745 ± 0.014^{B}	5.023 ± 0.012^{A}	5.035 ± 0.013^{A}	5.18 ± 0.012^{A}	5.23 ± 0.014^{A}
Oleic C 18 : 1	23.60 ± 0.011^{J}	43.962 ± 0.017^{A}	26.410 ± 0.016^{HI}	27.676 ± 0.017^{H}	29.521 ± 0.015^{HI}	31.32 ± 0.017^{FG}	32.36 ± 0.014^{F}	34.13 ± 0.012^{E}	37.367 ± 0.013^{D}	39.364 ± 0.012^{C}	41.672 ± 0.013^{B}
Linoleic C 18 : 2	49.988 ± 0.011^{A}	14.13 ± 0.019^{J}	45.643 ± 0.014^{B}	42.637 ± 0.014^{C}	39.10 ± 0.018^{D}	36.00 ± 0.014^{E}	33.30 ± 0.012^{F}	29.40 ± 0.012^{G}	25.20 ± 0.013^{H}	21.77 ± 0.012^{I}	17.714 ± 0.014^{J}
Linolenic C 18 : 3	0.233 ± 0.018^{A}	—	0.209 ± 0.015^{A}	0.197 ± 0.019^{AB}	0.192 ± 0.012^{B}	0.201 ± 0.019^{A}	0.116 ± 0.012^{BC}	0.093 ± 0.012^{CD}	0.069 ± 0.014D	0.046 ± 0.014^{E}	0.023 ± 0.019^{F}
Arachidonic C 20 : 0	0.355 ± 0.014^{A}	0.374 ± 0.012^{A}	0.355 ± 0.017^{A}	0.358 ± 0.015^{A}	0.360 ± 0.017^{A}	0.362 ± 0.014^{A}	0.364 ± 0.148^{A}	0.366 ± 0.157^{A}	0.368 ± 0.143^{A}	0.368 ± 0.012^{A}	0.372 ± 0.128^{A}
Total saturated fatty acids	25.07 ± 0.014^{F}	41.83 ± 0.019^{A}	26.708 ± 0.015^{F}	28.544 ± 0.019^{EF}	30.296 ± 0.154^{DE}	31.64 ± 0.017^{D}	33.50 ± 0.014^{B}	35.851 ± 0.014^{BC}	36.781 ± 0.014^{B}	38.40 ± 0.011^{AB}	40.186 ± 0.013^{A}
Total unsaturated fatty acids	74.992 ± 0.014^{A}	58.162 ± 0.017^{EF}	73.292 ± 0.014^{A}	71.456 ± 0.019^{A}	69.704 ± 0.148^{AB}	68.36 ± 0.015^{B}	66.50 ± 0.012^{C}	64.149 ± 0.013^{D}	63.219 ± 0.013^{D}	61.60 ± 0.013^{E}	59.824 ± 0.012^{EF}

Values are presented as mean ± SD ($n = 3$). A-B by various capital letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$)between the means followed.

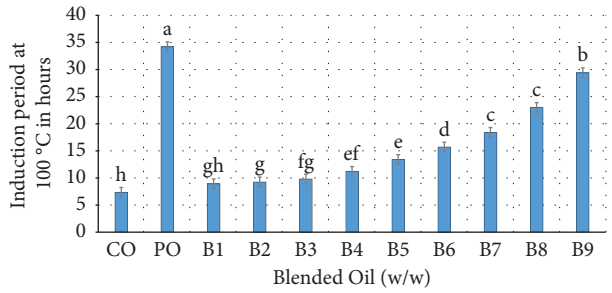

Figure 3: The stability of blended canola oil with palm olein at 100°C. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

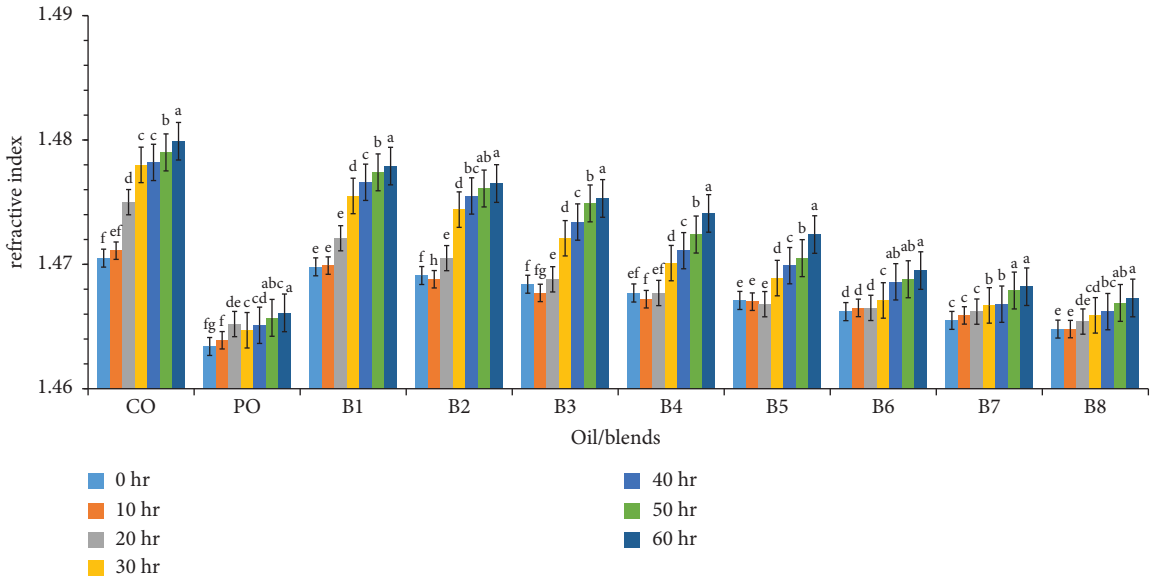

Figure 4: Effect of heating process at 180°C on the refractive index at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

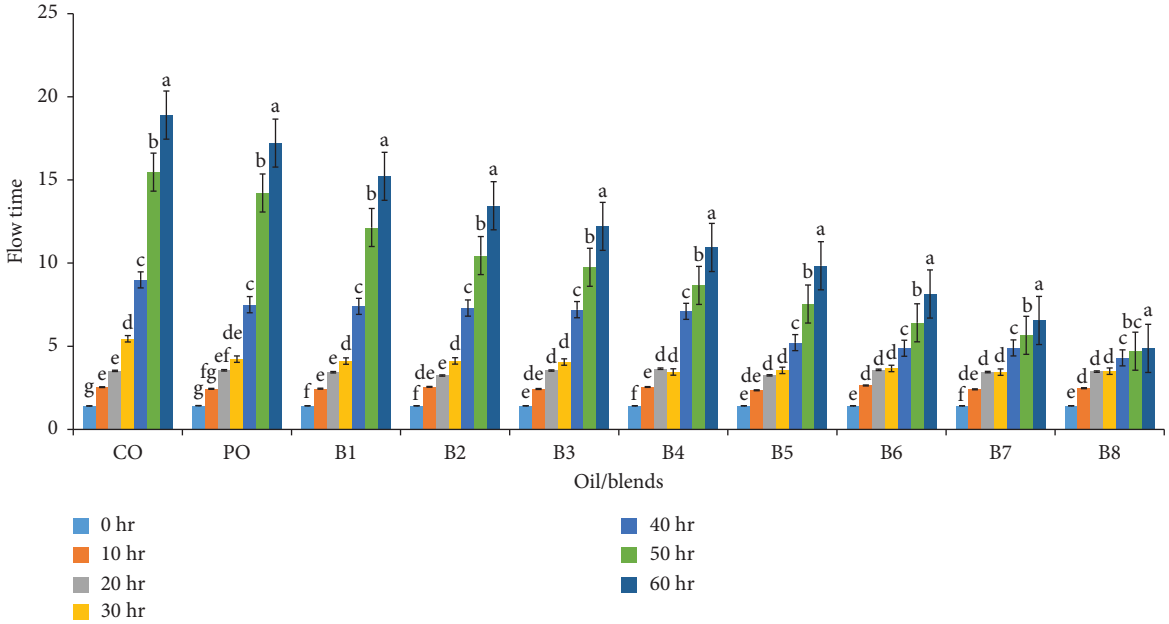

Figure 5: Effect of heating process at 180°C on the flow time at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

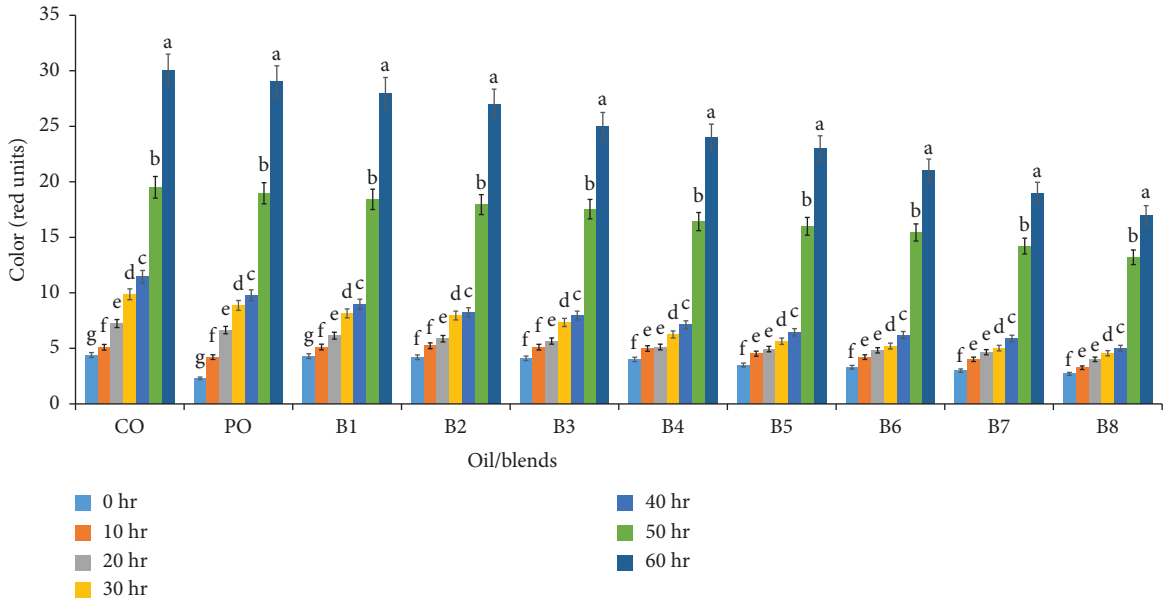

FIGURE 6: Effect of heating process at 180°C on color (color values) at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

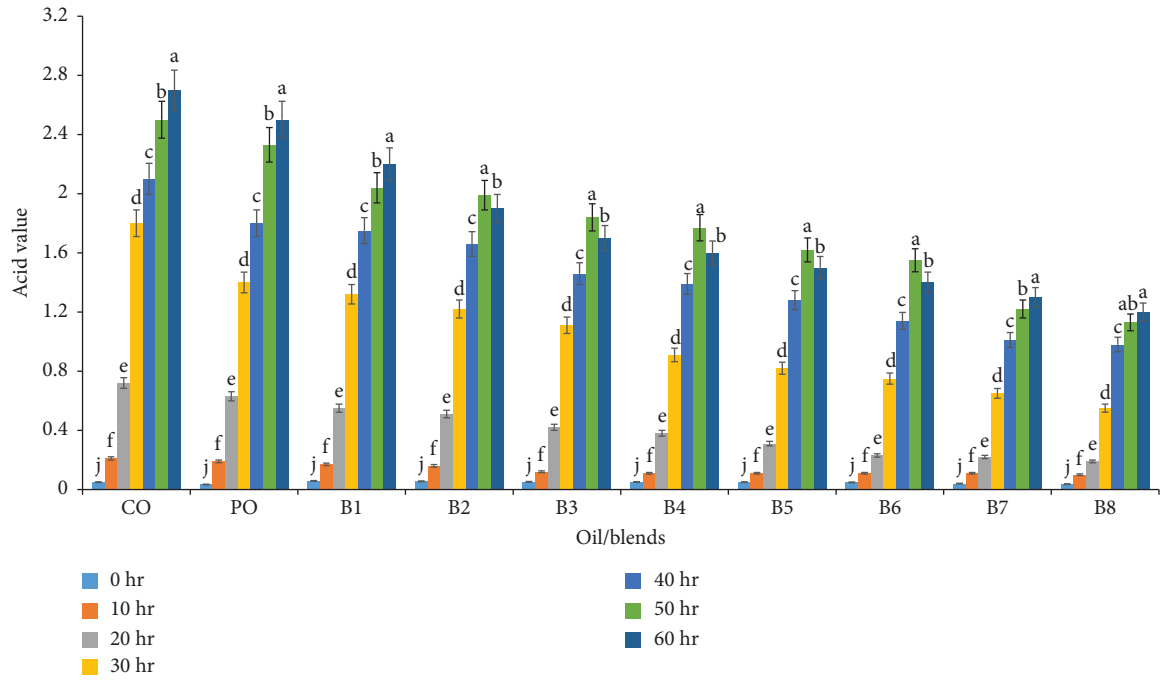

FIGURE 7: Effect of heating process at 180°C on the acid value at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

obtained by the authors of [24, 83, 84], who reported that palm olein had the lowest anisidine value compared to other vegetable oils (soybean and sunflower). Also, it could be observed that the maximum anisidine values were obtained after 20 h of heating. Subsequently, these remained almost stable until the end of the heating process. In general, it was found that blending canola oil with palm olein induced a remarkable improvement in the stability of the secondary oxidation state during the heating process at 180°C and up to 60 h because the anisidine value of the blended oil was lower than that of canola oil. Consequently, B8 was considered the best frying oil, followed by B7.

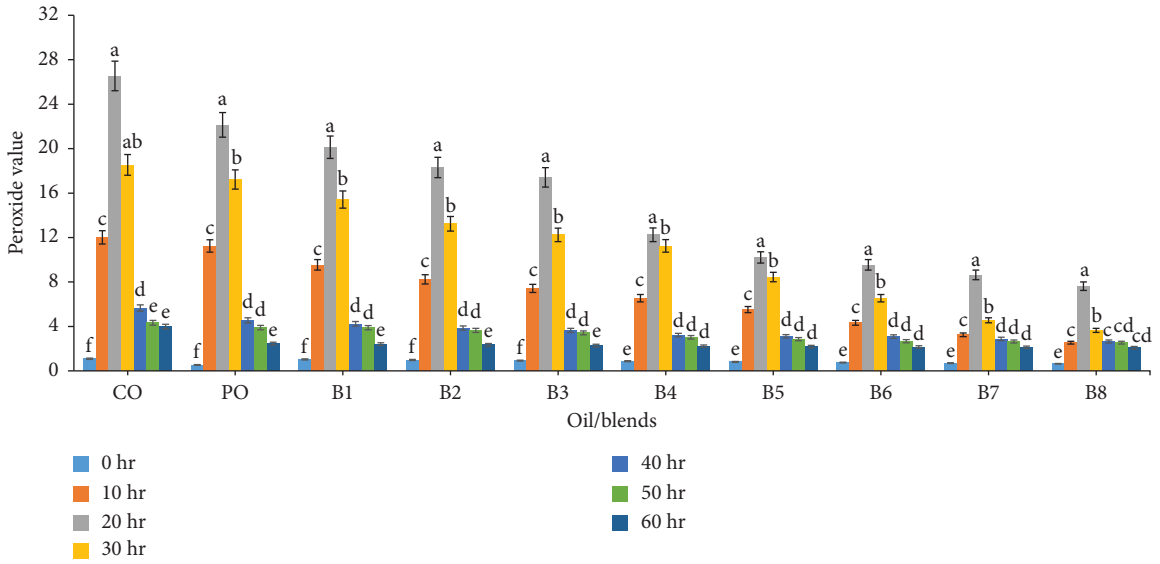

Figure 8: Effect of heating process at 180°C on the peroxide value at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

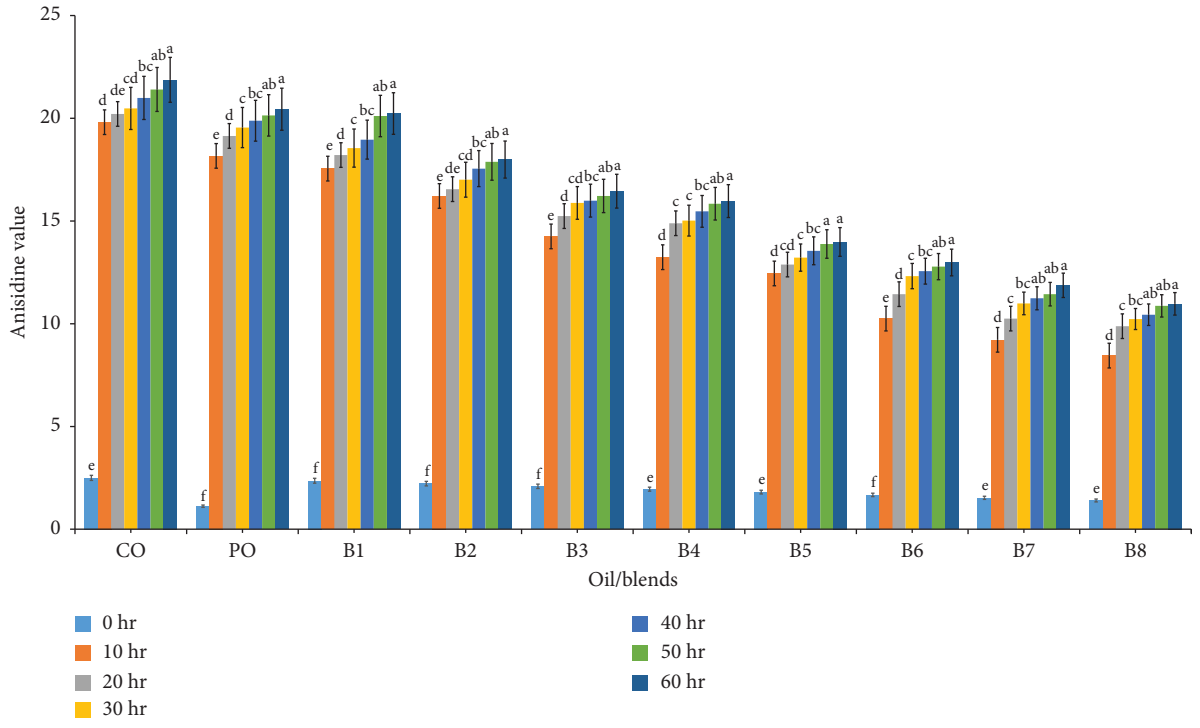

Figure 9: Effect of heating process at 180°C on the anisidine value at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

The data in Figure 10 indicate that the TOTOX value of the tested oils gradually increased until they reached their maximal values after 20 h of heating. As the heating period increased, the TOTOX value decreased substantially. These decreases might be due to the continuous oxidation of the secondary oxidative products to alcohols, aldehydes, and ketones and finally to low-molecular-weight fatty acids and/or epoxides and polymers. The iodine values of both canola oil and palm olein decreased gradually until the first 20 h, followed by a sharp decrease during the last 40 h. However, a significant decrease in the iodine value was observed in canola oil compared to that in palm olein. Thus, the changes

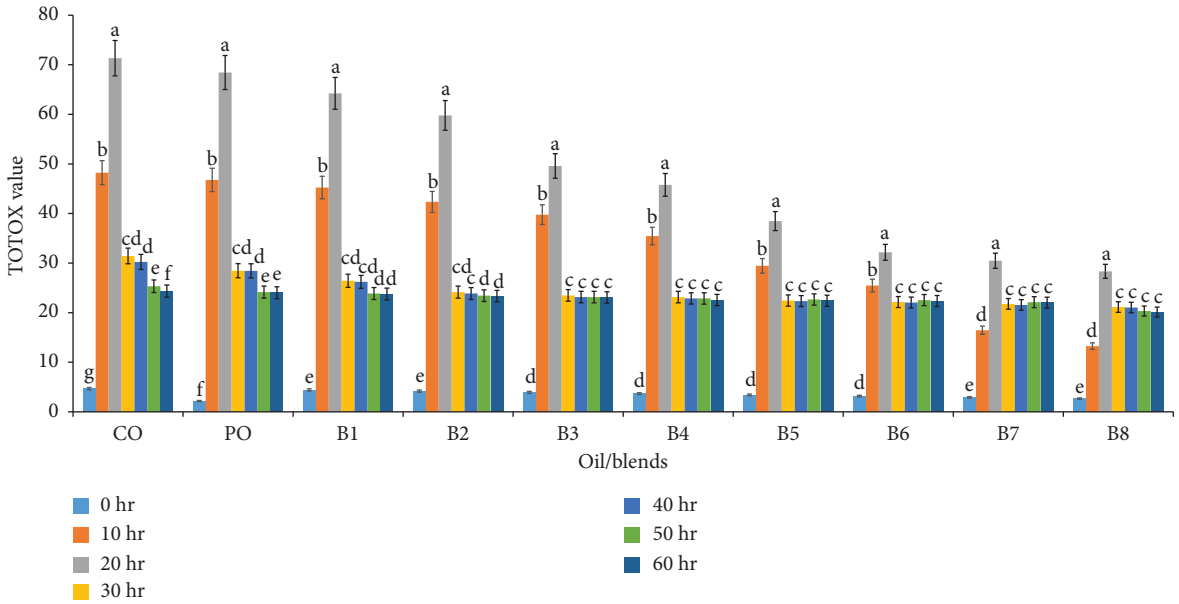

Figure 10: Effect of heating process at 180°C on the TOTOX value at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

in canola oil were compared with those in palm oil (Figure 11). These results indicated that successive heating at 180°C up to 60 h affected the iodine value of canola oil more markedly than that of palm olein. A similar observation was reported in [84–86].

3.6. Effect of Blending Canola Oil with Palm Olein on Its Frying Performance. Polymeric materials are one of the most important components of fat frying [86, 87]. The polymer contents in canola oil and palm olein after 60 h heating at 180°C were 10.32% and 7.17%, respectively (Figure 12). Blending canola oil with different proportions of palm olein decreased its tendency to form polymers during heating because the content of the blends was lower than that of canola oil throughout the heating process. The polymer content in sunflower seed oil increases continuously from 0.08% to 5.88% after 48 h of frying with daily replenishment [88]. The effect of frying up to 64 h on the polymer % of sunflower oil and its blend with palm olein (20%) was studied by the authors of [87, 88] who stated that fresh sunflower oil and its blend have 1.95% and 1.94% of the polymer, respectively, which means palm olein has zero polymer content. These values reached 6.11% and 6.01% after 56 h of frying. A smoke point of 130°C reached at 56h, which was cut off for sunflower oil. However its blend (20% palm olein) continued for 64 h of frying and the final polymer content reached to 7.02%.. Finally, it can be concluded that palm olein, when blended with canola oil, caused an improvement in the quality performance of fried oil up to 60 h at 180°C.

3.7. Effect of Repeated Frying on Flavour Scores of Potato Chips Fried in Canola Oil Blends with Palm Olein (PO). Table 3 summarizes the mean flavour scores of potato chips fried in canola oil. and, blended oils, B1 (80%CO+20%PO) and B2 (70% CO+ 30% PO) for five days. These results showed that at each frying batch for five days, the flavour scores of all fried potato chips were acceptable. Generally, increasing the frying number or frying days decreased the flavour scores of potato chips fried with all oils. This may be attributed to more oil degradation and more surfactants, causing excessive contact between the fried chips and oil [89, 90]. Potato chips fried in 30% palm olein + 70% canola oil were preferred by the taste panel over similar chips fried in either canola oil or 20% palm olein + 80% canola oil. This means that olein improved the acceptability when used with canola oil by up to 30% during the frying process. A taste panel preferred potato chips fried in palm olein and stored at room temperature over similar chips fried in canola oil [89, 91]. As such, palm olein can be blended with canola oil to improve

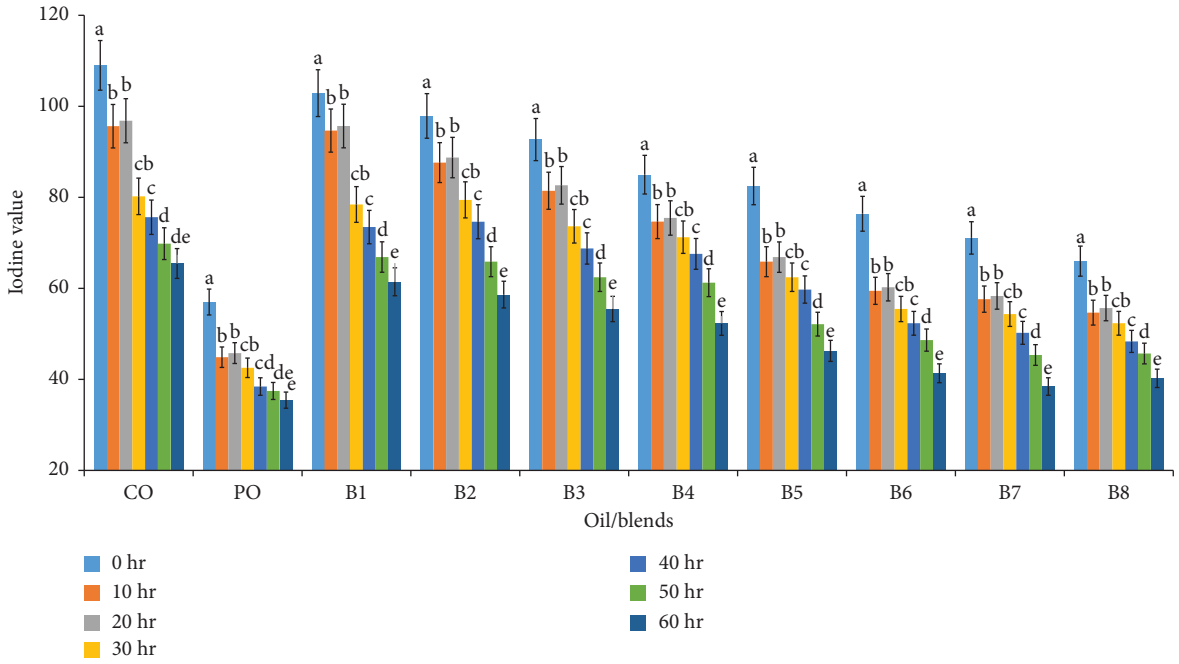

Figure 11: Effect of heating process at 180°C on the iodine value at 25°C of canola oil, palm olein, and other blends. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

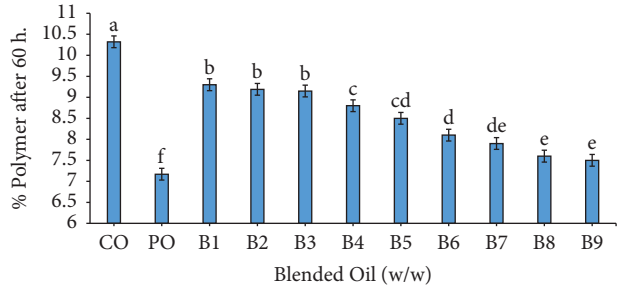

Figure 12: Effect of heating at 180 C for 60 h on the frying performance of canola olein and its blends with palm olein. Values are presented as mean ± SD ($n = 3$). a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed.

its stability during frying and prolong the shelf life of fried products. In other words, both the taste of the fried items and their shelf life could be improved by blending canola oil with palm olein.

3.8. Effect of Blending Canola Oil with Palm Olein on the Formation of Toxic Substances during Frying and Heating. The results in Table 4 represent the degree of inhibition zone affected by the formation of biologically active substances after 60 h of oil heating. In palm olein, no biologically active substances were formed after 60 h of heating. In the case of canola oil, biologically active substances were pronounced (+++). These results indicate that palm olein has higher stability than canola oil because of the presence of tocotrienols and tocopherols. In addition, a balanced fatty acid profile of 50% saturated and 50% unsaturated fatty acids was observed.

The latter fatty acid is mainly oleic acid [16, 92]. However, the formation of these biologically active substances was decreased when the percentage of palm olein increased and reached a slight (+) case in the case of 60% CO + 40% PO w/w after 60 h of heating. In this respect, the authors of [90, 93] found that a diameter of inhibition zone of 98 mm was formed after 64 h of excessive frying of the blend (80% sunflower oil + 20% palm olein, w/w). Such blends did not form any toxic substances up to 56 h of frying, whereas in sunflower oil, biologically active substances were formed after 40 h of frying.

Table 3: Effect of repeated frying on flavour scores of potato chips fried in canola oil blends with palm olein (PO).

Fatty acid	Frying batch										
	First			Second			Third			Fourth	
	CO	B1	B2	CO	B1	B2	CO	B1	B2	CO	B1
1st day	2.8 ± 0.188^{Cb}	3.2 ± 0.17^{Bbc}	4.2 ± 0.17^{Aa}	2.72 ± 0.47^{Cb}	2.62 ± 0.25^{Cb}	3.02 ± 0.14^{Bb}	2.62 ± 0.45^{Cb}	3.42 ± 0.36^{Ba}	4.02 ± 0.64^{Aa}	2.82 ± 0.94^{Ca}	4.22 ± 0.14^{Aa}
2nd day	3.6 ± 0.189^{Ba}	4.2 ± 0.189^{Aa}	4.42 ± 0.66^{Aa}	3.22 ± 0.45^{BCa}	3.02 ± 0.98^{Ca}	3.62 ± 0.48^{Bb}	3.02 ± 0.12^{Ca}	3.62 ± 0.45^{Ba}	4.02 ± 0.84^{Aa}	2.62 ± 0.78^{Da}	3.02 ± 0.96^{Cb}
3rd day	3.6 ± 0.187^{a}	4.0 ± 0.189^{ABa}	4.62 ± 0.42^{Aa}	3.42 ± 0.62^{Ba}	3.82 ± 0.45^{Ba}	4.42 ± 0.87^{Aa}	3.42 ± 0.47^{Ba}	3.82 ± 0.42^{Ba}	4.02 ± 0.87^{Aa}	2.82 ± 0.94^{a}	3.62 ± 0.87^{Bab}
4th day	2.4 ± 0.183^{Bb}	3.4 ± 0.189^{Ab}	3.62 ± 0.88^{Ab}	2.42 ± 0.62^{Bb}	3.02 ± 0.98^{Aa}	3.42 ± 0.97^{Ab}	2.22 ± 0.36^{Bb}	2.82 ± 0.84^{ABb}	3.22 ± 0.97^{Ab}	2.02 ± 0.552^{Bab}	2.82 ± 0.945^{ABc}
5th day	2.4 ± 0.187^{Bb}	3.2 ± 0.187^{Abc}	3.62 ± 0.78^{Ab}	2.22 ± 0.23^{BCb}	3.02 ± 0.87^{ABa}	3.62 ± 0.74^{Ab}	2.02 ± 0.12^{CDb}	2.62 ± 0.56^{Bb}	3.02 ± 0.78^{ABb}	1.82 ± 0.654^{Cb}	2.42 ± 0.91^{Bc}

Values are presented as mean ± SD ($n = 3$). A-B-C by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed. a-b-c by various small letters in the same row, the Tukey test shows a significant difference ($p \leq 0.05$) between the means followed. B1: 80% CO + 20% PO. B2: 70% CO + 30% PO.

Table 4: Stability of blended canola olein with palm olein at 100°C.

Blended oil (w/w)	Zero	After 60 h heating
CO	—	+++
PO	—	—
10% PO + 90% CO	—	+++
20% PO + 80% CO	—	++
30% PO + 70% CO	—	+
40% PO + 60% CO	—	+

—: no formation of biologically active substances; +: slight formation of biologically active substances; ++: pronounced formation of biologically active substances (amounted to 52 mm diameter of inhibition zone); +++: very pronounced formation of biologically active substances (amounted to up to 80 mm diameter of inhibition zone).

4. Conclusion

Blending palm oil with canola oil in different proportions resulted in better physicochemical properties. Blending canola oil with palm olein improved its quality during hydrolysis and oxidative processes, as indicated by the tested parameters. Although palm olein contains more saturated fatty acids and is highly stable and canola oil is rich in unsaturated fatty acids and has low oxidative stability, the oil blends of palm and canola oil showed higher oxidative stability than pure canola oil and a higher proportion of unsaturated fatty acids than pure palm oil. The polymer content in canola oil and palm olein after 60 h of heating at 180°C was 10.32% and 7.17%, respectively, and it decreased with increasing percentage of palm oil for blends from B1–B9 indicating that the blends performed better than canola oil alone in terms of polymer content formation. Palm oil did not show any formation of biologically active substances, whereas canola oil showed a pronounced formation of biologically active substances. However, the formation of these biologically active substances decreased with increasing palm olein percentage in the blended oils.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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