

Effect of frying process on fatty acid composition and iodine value of selected vegetable oils and their blends

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Abstract: The main objective of the present study was to investigate the effects of the frying media and storage time on the fatty acid composition (FAC) and iodine value (IV) of deep-fat fried potato chips. The frying experiment was conducted at 180°C for five consecutive days. Six frying media were considered as the main treatments: refined, bleached, deodorized (RBD) palm olein (A), canola oil (C), RBD palm olein/ sesame oil (AB, 1:1 w/w), RBD palm olein/canola oil (AC, 1:1, w/w), sesame oil/canola oil (BC, 1:1, w/w), and RBD palm olein/ sesame oil/canola oil (ABC, 1:1:1, w/w/w). The initial degrees of unsaturation of the consumed oils, A, C, AB, AC, BC, and ABC, were 58.6, 94.0, 68.0, 72.2, 87.7, and 75.8 (g/100 g), respectively. The fatty acid analysis showed that there was a decrease in both the linolenic acid (C18:3) and linoleic acid (C18:2) contents, whereas the palmitic acid (C16:0) increased with a prolonged frying time. The chemical analysis showed that there was a significant ($p < 0.05$) difference in terms of the IV for each frying oil during the five consecutive days of frying (day 0 to 5). Oil C had the least stability in terms of deep-fat frying due to a high level of unsaturated fatty acids. Conversely, oil AC had the best stability due to the smallest reduction of the C18:2/C16:0 ratio and the IV.

Keywords: Deep-fat frying, fatty acid composition, iodine value, palm olein, canola oil, sesame oil

Introduction

Deep-fat frying is one of the most common processes in the preparation and manufacture of foods. The aim of deep-fat frying is to seal the food by immersing it in hot oil so that all the flavors and juices are retained within the crispy crust. The quality of the products cooked using this method depends not only on the frying conditions, such as the temperature of the heated oil, frying time, food weight, and frying oil volume, but also on the types of oil and the kinds of foods used (Varela, 1994). During deep-fat frying, the fat is continuously being exposed to elevated temperatures (150-180°C) in the presence of the substrates air and water. A complex series of reactions such as hydrolysis, oxidation, polymerization, isomerization, and cyclization takes place during the deep-fat frying. These reactions result in the formation of volatile and nonvolatile compounds affecting the sensory, functional, and nutritional qualities of the frying oil.

In general, deep-fat frying decreases the content of unsaturated fatty acids in frying fat and oil.

Researchers (Tynek *et al.*, 2001; Cuesta *et al.*, 1991) have found a relative loss of the C18:2 fatty acid and a decrease in the iodine value of oil after heating due to more intensive thermo-oxidative transformations that occur compared to heated oil containing food. The decrease in the iodine value can be attributed to the destruction of double bonds by oxidation, scission, and polymerization. According to previous studies (Orthoefer *et al.*, 1996; Tyagi and Vasishtha, 1996; Choe and Min, 2007), the heat treatment causes the oxidative rancidity resulting in an increase in the free fatty acids. This is why heated and unheated fats and oils should be monitored by means of analysis, e.g., the FAC and IV indicating the degradation of the FAs. Usually many oils can be used for frying, e.g., palm oil, corn oil, cotton oil, soya oil, canola oil, sesame oil, and sunflower oil (Valenzuela *et al.*, 2003). Several different oils are usually blended to get a healthy oil mixture. Therefore, the formulation should be low in its content of linoleic and linolenic acids, whereas it should contain a high level of natural antioxidants to be stable in the heating process.

RBD palm olein is widely used as cooking

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oil. It perfectly blends with other widely popular vegetable oils. For example, refined palm olein is blended with rice bran oil in Japan and blended with groundnut oil in Malaysia. Like palm oil, RBD palm olein is also widely used as a frying oil, and much of its popularity is due to its good resistance to oxidation and formation of breakdown products at frying temperatures. Partial hydrogenation of oils is a common way to reduce the content of the linoleic and linolenic acids; however, RBD palm olein has a low content of linoleic and linolenic acids so that blending it with other oils is an alternative approach to partial hydrogenation. Furthermore, blending oils does not form *trans* fatty acid isomers (Kun, 1990).

Canola, an important economic cultivar in Canada has become the world's third leading source of vegetable oil (Firestone, 1999). Ackman, (1990) compared the nutritional advantages of canola oil with other common oils. The fatty acid composition of canola oil is most favorable in terms of the health benefits. Indeed, canola oil is high (61%) in monounsaturated fatty acid (oleic acid). Oleic acid reduces serum cholesterol levels and "bad" (LDL) cholesterol levels, while it does not affect levels of "good" (HDL) cholesterol.

Sesame (*Sesamum indicum* L) is an important source of edible oil. The oil shows a remarkable stability despite being highly unsaturated. Sesame seeds are used in confectioneries and are considered to be a healthy food (Namiki, 1995). Many studies have investigated the health-promoting effects of sesame. As shown in a previous study (Kang *et al.*, 1999; Sugano *et al.* 1990), it has a hypocholesterolemic effect, a suppressive effect on chemically induced cancer, and anti-aging properties. Furthermore, sesame oil has sesamin and sesamol, which are natural antioxidants (Kang *et al.*, 1999; Sugano *et al.*, 1990; Yamashita *et al.*, 1995). The main objective of the present study was to investigate the effects of the type of frying oil and storage time on the fatty acid composition and iodine value of frying media. This study was conducted to monitor the changes in the fatty acid composition of selected oils (i.e., RBD palm olein, canola, and sesame) and their combinations under the frying conditions.

Materials and Methods

Materials

Refined, bleached, and deodorized (RBD) palm olein, sesame oil, and canola oil were obtained from a local supermarket (Selangor, Malaysia). Three different oils were used to prepare six various frying

media: RBD palm olein oil (A), canola oil (C), RBD palm olein/sesame oil (1:1, w/w) (AB), RBD palm olein/canola oil (1:1, w/w) (AC), sesame/canola oil (1:1, w/w) (BC), and RBD palm olein/sesame/canola oil (1:1:1, w/w/w) (ABC). Potatoes (*Solanum tuberosum* L., var. 'Russet Burbank') were bought from a local supermarket (Selangor, Malaysia). The fatty acid methyl ester (FAME) standards were purchased from Sigma-Aldrich (St Louis, MO, USA). Petroleum-ether, 2-Propanol, Acetic acid glacial, and n-Hexane (GLC) were supplied by Fisher Scientific (Pittsburgh, PA, USA). All other analytical and GC grade chemicals and solvents were supplied by Merck (Darmstadt, Germany).

Frying process

Fresh potatoes were peeled and sliced to a thickness of 2 mm using a mechanical slicer. They were kept in distilled water at room temperature ($25 \pm 1^\circ\text{C}$). They were then slightly blotted dry with tissue paper before weighing into a 100 g batch for the frying process. In this study, 3.5 kg of each frying medium (A, C, AB, AC, BC, and ABC) was put into a Jakad batch fryer (ISD-306, Selangor, Malaysia). The temperature was then raised to 180°C over 20 min. The frying process was started 20 min after the temperature reached 180°C . A batch of 100 g of raw, sliced potato was fried for 2.5 min at 180°C with 17.5 min intervals between for a period of 3.5 h per day, for five consecutive days. This is equivalent to 10 frying sessions per day, and therefore 50 frying sessions after five consecutive days. The fryer was left uncovered throughout the 3.5 h frying period (Che Man & Tan, 1999). At the end of the tenth frying, the lid of the fryer was put on after switching off the fryer, and the oil was allowed to cool overnight.

In this study, after the tenth frying of each day, 120-g of oil samples at 60°C were collected in amber bottles for further analysis (iodine value). All of the samples were stored under nitrogen at -20°C . The chemical analysis of the oil was carried out immediately after the frying experiment. Fresh oil was not added to the frying vessel during the frying process. The potato chips obtained from the frying process were stored in sealed plastic and kept under -20°C for further analysis (fatty acid composition). The same procedure was applied to all six formulations.

Extraction of oil from fried potato chips

The potato chips were ground to make a uniform powder. Ten grams of potato powder was weighed in a thimble and plugged with a wad of cotton wool,

and then the Soxhlet apparatus (250 ml) was used to extract the oil from the potato powders. The extraction was done with 150 ml of petroleum-ether (40–50°C) as a solvent for 6 hours. The solvent was evaporated with a rotary vacuum evaporator (NE-1001, Japan), and the remaining solvent was taken away by putting the container in an oven at 103±2°C for 2 hours. Finally, the oil was collected in an amber bottle and kept under nitrogen at -20°C. This procedure was performed in duplicate for each sample (PORIM, 1995).

Fatty acid composition (FAC)

A Hewlett-Packard 6890 GC equipped with a flame ionization detector (FID) and a BPX70 column (SGE International Pty, i.d. = 0.32 mm, length = 30 m, film thickness = 0.25 µm, Victoria, Australia) was employed for the qualitative and quantitative analyses of the fatty acid composition. The FAC of oil extracted from fried potato chips was determined in this study. The FAC was determined by the conversion of oil to fatty acid methyl esters (FAMES) using the method of Cocks and Van Rede (1966). The FAMES were prepared by adding 950 µl of n-hexane to 50 mg of oil followed by the addition of 50 µl of sodium methoxide. The mixture was vortexed for 5 s and allowed to equilibrate for 5 min. The top layer (0.5 µl) was injected into a gas chromatograph (GC). The GC injection port was equipped with a 0.5 mm i.d. liner (Supelco) to minimize peak broadening. The oven temperature was programmed at 115°C, then ramped up to 180°C at 6°C/min and held for 10 min at 180°C. Helium was used as the carrier gas. The detector temperature was set at 250°C. For the GC-FID analysis, the injection was performed at 220°C under split mode (1:20). The data are considered as the percent of the normalized peak area of all the identified FAMES and expressed as the mean value of four individual measurements from two replicates.

Iodine value analyses

The iodine value (IV) of frying oil was determined according to the standard methods in the PORIM Test Methods (1995).

Statistical analysis

The data obtained from the experimental measurements were subjected to a one-way analysis of variance (ANOVA) to determine the significant differences among the treatments. Significance was defined at $p < 0.05$. The percentages of the identified fatty acids, iodine value, and ratio of C18:2/C16:0

were considered as the response variables in this study. All of the experiments and/or measurements were carried out in duplicate and reported as the mean ± SD of the independent trials. The significant differences ($p < 0.05$) between the means were further determined by Duncan's multiple-range test. The data analysis was performed using SPSS Version 15.0 (SPSS Inc., USA).

Results and Discussion

Fatty acid composition (FAC)

The FACs of the oils extracted from fried potato chips are shown in Table 1. For all six fresh frying oils, the most predominant fatty acids (FAs) were palmitic (7.4-32.1 g/100 g), oleic (42.5-64.2 g/100 g), and linoleic (16.6-31.9 g/100 g) acids. The RBD palm olein had the smallest amount of polyunsaturated fatty acids (PUFAs) (16.6 g/100 g) compared to the PUFA content of the other five frying media, namely, AC (21 g/100 g), AB (25.8 g/100 g), ABC (27 g/100 g), C (29.1 g/100 g), and BC (37.1 g/100 g) (Table 1). On the other hand, the canola oil (C) showed the highest content of oleic acid (64.2 g/100 g). High amounts of monounsaturated fatty acids (MUFAs) in oils are associated with a decreased risk of coronary heart disease. Thereby, oil with high amount of MUFA induces a desirable effect on the health benefits (Mensink and Katan, 1990).

Table 1 shows the highest level of FA in the RBD palm olein (A) as C18:1 (45.2 g/100 g), whereas the other FAs in decreasing order were C16:0, C18:2, and C18:0. The major FAs in frying medium C were as follows: C18:1, C18:2, C18:3, and C16:0. According to Crews *et al.* (2006), FACs of sesame oil were decreasing in the order: C18:2, C18:1, C16:0, and C18:0.

The changes in the FAC of six different frying media during the five days of the frying process are given in Table 1. It was found that there was a decrease in both the linolenic acid (C18:3) and linoleic acid (C18:2) contents, whereas the palmitic acid (C16:0) increased with a prolonged frying time in all six oil formulations. Min and Bradley (1992) reported the relative auto-oxidation rate of oleic, linoleic, and linolenic acids as 1:40 to 50:100 on the basis of the oxygen uptake. The reaction rates between O₂ and C18:0, C18:1, C18:2, and C18:3 are 1.2×10^4 , 5.3×10^4 , 7.3×10^4 , and 10.0×10^4 M⁻¹s⁻¹, respectively (Vever-Bizet *et al.*, 1989). The relative reaction rate of C18:3 with oxygen is much faster than that of C18:2 and C18:1. Therefore, the highest reduction in C18:3 and the lowest reduction in C18:1 are

expected. Table 1 confirms this expectation. Indeed, in frying medium A, C18:2 showed the highest reduction (25%) in FA. The decrease in C18:2 could be explained by the oxidation of unsaturated fatty acid (USFA), which changes to primary and secondary oxidation products during the frying process. In frying medium C, the highest reduction was in C18:3 (22.4%). In other formulations, the largest decrease among the FAs belonged to C18:3. These reductions were formed as follows: AC (17.5%), BC (10%), and ABC (14.3%). The decreases in C18:2 in the other oil formulations were C (6.2%), AB (11.2%), AC (10.1%), BC (9.7%), and ABC (7.8%). In all of the oil treatments, the smallest decrease in C18:3 belonged to BC (10%), and the highest decrease was observed in oil C (22.4%). The lowest reduction in C18:2 was seen in oil C (6.2%), and the largest increase was for oil A (25%). Regarding the changes in the C18:3 and C18:2, oil BC showed the most stability during the deep-fat frying process.

According to Table 1, the amounts of initial (USFAs) in the A, C, AB, AC, BC, and ABC formulations were 58.6, 94.0, 68.0, 72.2, 87.7, and 75.8 (g/100 g), respectively. The amounts of reduction in the USFAs in all of the oils were A (12.4%), C (3%), AB (3.1%), AC (2.6%), BC (4.4%), and ABC (2.2%). Oils A (12.4%) and ABC (2.2%) showed the highest and the lowest decrease in the amounts of USFAs, respectively. This implies that blending oils avoids a sharp decrease in the USFAs of oil formulations and that, consequently, the blended oils have a higher stability in the deep-fat frying process than unmixed oils do.

Based on Table 1, the amount of C18:1 was decreased in oil A (10.8%) and oil C (0.2%), while it was increased in AB (28%), AC (0.4%), BC (5.5%), and ABC (1.4%). This could be due to the breaks in linkages of C18:3 and C18:2. Then, C18:3 and C18:2 would change into C18:1 and other FAs. These data show that the only increase of C18:1 happened in blended oils whereas it was decreased in all of the unmixed oils. This is also another reason to make the blended oils more stable against thermal process than the unmixed ones.

As shown in Table 1, frying increased the amount of C18:0 in all of the formulations as follows:

C (35%) > AB (9.8%) > ABC (9.3%) > BC (7%) > AC (2.9%) > A (2.3%)

The amount of C16:0 was increased in all oil treatments: A (34.6%), C (41%), AB (5.8%), AC (7.7%), BC (8.1%), and ABC (7%). The largest increase belonged to oil C (4%), and the smallest was for AB (5.8%). The increase in C18:0 and C16:0 could

be related to the breaking of double and triple bonds in the USFAs (i.e., mono-, di-, and polyunsaturated fatty acids), which could then be transformed into FAs with the same number of carbons or a shorter chain.

The ratios of C18:2/C16:0 are presented in Table 1. In all of the treatments, these ratios declined during the five consecutive days of frying. The percent reductions of the ratio C18:2/C16:0 in the A, C, AB, AC, BC, and ABC oil treatments were 33.3, 34, 20, 14.3, 16.3, and 15.4, respectively. C18:2 and C16:0 are usually used as indicators for determining the degree of fat deterioration because linoleic acid is more susceptible to oxidation, whereas C16:0 is more stable. Therefore, the ratio of C18:2/C16:0 was also used to indicate the degree of oxidative deterioration in the frying oil samples.

The smallest change (decrease) in the C18:2/C16:0 ratio from day 0 to 5 of each of the oil treatments belonged to the AC (14.3%) oil formulation. The RBD palm olein had the lowest amount of PUFAs among A, B, and C, and thus, the presence of RBD palm olein in blended oils contributes to a mild decrease in the C18:2/C16:0 ratio. Indeed, Kun (1990) indicated that blending RBD palm olein into other vegetable oils reduces the content of C18:2 and C18:3 to a level where the effect is similar to partial hydrogenation without forming any discernible *trans* free fatty acid isomers. It is imperative to note that the unmixed RBD palm olein had a high decrease in the C18:2/C16:0 ratio, while the effect of blending it with other oils had a milder decrease in the ratio than in the individual oil. This result may be explained by observing the changes made in the denominator (i.e., C16:0). Indeed, the decreases made in C16:0 (both in A and C) are the highest among all of the frying oils. This means that the mixture of the oils does noticeable change the chemical reactions that occur during the frying process. The lowest change in the C18:2/C16:0 ratio in the blended oils confirms the claim of this study that a mixture of oils can result in more stable oils than the unmixed oils.

In this study, the largest reduction in the ratio of C18:2 over C16:0 from day zero to the fifth day of frying belonged to medium C (34%), which has a high level of PUFAs. Despite the fact that the frying medium BC had the highest amount of PUFAs, it was ranked fourth in the reduction (16.3%) of the C18:2/C16:0 ratio. This indicates the role of the natural antioxidants of sesame oil in the protection against oxidation in frying medium BC. Yen (1991) also mentioned that sesame oil is good at blending with other major vegetable oils such as soybean oil, and soybean oil is a major edible oil. In spite of remarkable

Table 1. Changes in fatty acid composition (g/ 100 g oil) during deep fat frying

Oil	Day	Fatty Acid Composition ^e														C18:2/ C16:0	Total Unsaturation
		C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C20:0	C20:1	C20:0	C20:1		
A*	0	1.5±0.1 ^a	ND	32.1±0.5 ^d	0.8±0.0 ^a	4.4±0.6 ^a	46.2±0.7 ^c	11.6±1.1 ^d	ND	ND	ND	ND	ND	ND	ND	0.3±0.0 ^c	58.6 ^d
	1	1.1±0.1 ^b	ND	40.3±0.8 ^{bc}	ND	4.3±0.1 ^a	43.5±0.5 ^b	10.9±0.1 ^d	ND	ND	ND	ND	ND	ND	ND	0.3±0.0 ^c	54.4 ^c
	2	1.1±0.0 ^b	ND	39.9±0.7 ^c	ND	4.4±0.1 ^a	43.7±0.5 ^b	10.9±0.1 ^d	ND	ND	ND	ND	ND	ND	ND	0.3±0.0 ^c	54.6 ^c
	3	1.1±0.1 ^b	ND	42.1±1.6 ^{ab}	ND	4.4±0.1 ^a	42.6±1.1 ^{ab}	9.8±0.2 ^b	ND	ND	ND	ND	ND	ND	ND	0.2±0.0 ^b	52.6 ^b
	4	1.1±0.0 ^b	ND	41.8±0.1 ^{abc}	ND	4.2±0.1 ^a	43.1±0.3 ^b	9.5±0.2 ^b	ND	ND	ND	ND	ND	ND	ND	0.2±0.0 ^{ab}	52.6 ^b
C*	5	1.3±0.1 ^b	ND	43.2±1.7 ^a	1.4±0.0 ^a	4.5±0.1 ^a	41.2±0.8 ^a	8.7±0.1 ^a	ND	ND	ND	ND	ND	ND	ND	0.2±0.0 ^a	51.3 ^a
	0	ND	ND	3.9±0.0 ^c	ND	2.0±0.0 ^a	64.0±0.1 ^a	20.8±0.2 ^c	8.2±0.1 ^d	0.5±0.1 ^a	1.0±0.0 ^a	1.0±0.0 ^a	0.5±0.1 ^a	1.0±0.0 ^a	5.3±0.1 ^d	94.0 ^d	
	1	ND	ND	4.8±0.2 ^b	ND	2.4±0.0 ^a	62.9±0.1 ^d	19.4±0.1 ^d	7.7±0.1 ^c	0.5±0.0 ^a	1.1±0.0 ^a	1.1±0.0 ^a	0.5±0.0 ^a	1.1±0.0 ^a	4.0±0.2 ^c	91.5 ^b	
	2	ND	ND	5.2±0.2 ^{ab}	ND	2.7±0.0 ^a	63.1±0.0 ^c	19.9±0.1 ^c	7.7±0.2 ^c	0.7±0.0 ^a	1.1±0.0 ^a	1.1±0.0 ^a	0.7±0.0 ^a	1.1±0.0 ^a	3.8±0.1 ^b	91.8 ^c	
	3	ND	ND	5.2±0.1 ^{ab}	ND	2.7±0.0 ^a	63.0±0.4 ^{bcd}	19.8±0.1 ^c	7.6±0.2 ^c	0.6±0.0 ^a	1.1±0.0 ^a	1.1±0.0 ^a	0.6±0.0 ^a	1.1±0.0 ^a	3.8±0.1 ^b	91.5 ^b	
AB*	4	ND	ND	5.6±0.0 ^a	ND	2.6±0.1 ^a	63.5±0.1 ^b	19.3±0.1 ^b	7.3±0.0 ^b	0.7±0.0 ^a	1.1±0.1 ^a	1.1±0.1 ^a	0.7±0.0 ^a	1.1±0.1 ^a	3.5±0.0 ^a	91.2 ^a	
	5	ND	ND	5.5±0.3 ^a	ND	2.7±0.1 ^a	63.9±0.1 ^a	19.5±0.1 ^a	6.7±0.1 ^a	0.7±0.0 ^a	1.1±0.1 ^a	1.1±0.1 ^a	0.7±0.0 ^a	1.1±0.1 ^a	3.5±0.1 ^a	91.2 ^a	
	0	0.6±0.0 ^a	ND	25.8±0.1 ^a	0.2±0.0	5.1±0.2 ^a	42.5±0.5 ^a	25.0±0.7 ^e	0.3±0.0 ^a	0.5±0.0 ^a	ND	ND	0.5±0.0 ^a	ND	1.0±0.0 ^d	68.0 ^c	
	1	0.7±0.1 ^a	ND	27.0±1.8 ^a	ND	5.5±0.2 ^b	43.5±1.0 ^{abc}	23.6±0.6 ^{dc}	ND	ND	ND	ND	ND	ND	0.9±0.1 ^{bc}	67.1 ^{abcd}	
	2	0.6±0.0 ^a	ND	26.1±0.4 ^a	ND	5.7±0.1 ^b	43.1±0.1 ^b	23.8±0.1 ^d	ND	ND	ND	ND	ND	ND	0.9±0.0 ^c	66.9 ^d	
AC*	3	0.6±0.0 ^a	ND	25.9±0.2 ^a	ND	5.7±0.0 ^b	43.8±0.1 ^c	23.1±0.0 ^c	0.2±0.0 ^a	0.7±0.0 ^a	ND	ND	0.7±0.0 ^a	ND	0.9±0.0 ^{bc}	67.1 ^c	
	4	0.6±0.0 ^a	ND	26.2±0.4 ^a	ND	5.9±0.1 ^c	44.0±0.3 ^c	22.6±0.1 ^b	ND	0.7±0.0 ^a	ND	ND	0.7±0.0 ^a	ND	0.9±0.0 ^b	66.6 ^b	
	5	0.6±0.0 ^a	ND	27.3±0.1 ^a	ND	5.6±0.1 ^b	43.7±0.1 ^c	22.2±0.1 ^a	ND	0.6±0.0 ^a	ND	ND	0.6±0.0 ^a	ND	0.8±0.0 ^a	65.9 ^a	
	0	0.6±0.0 ^b	ND	23.4±0.9 ^b	0.2±0.0 ^a	3.4±0.0 ^a	51.5±0.3 ^a	15.9±0.3 ^c	4.0±0.2 ^c	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.5±0.0 ^a	0.6±0.0 ^a	0.7±0.0 ^{bc}	72.2 ^c	
	1	0.6±0.0 ^b	ND	22.9±0.4 ^b	ND	3.6±0.0 ^a	52.1±0.3 ^b	15.8±0.2 ^c	4.0±0.1 ^c	0.6±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.7±0.0 ^c	72.5 ^c	
AC*	2	0.6±0.0 ^b	ND	23.4±0.4 ^b	ND	3.7±0.1 ^a	53.1±0.3 ^c	15.7±0.3 ^c	3.7±0.3 ^{bc}	ND	ND	ND	ND	ND	0.8±0.0 ^{bc}	72.5 ^c	
	3	0.6±0.0 ^b	ND	23.3±0.4 ^b	ND	3.7±0.0 ^a	52.3±0.1 ^b	15.1±0.3 ^b	3.8±0.1 ^b	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.5±0.0 ^a	0.6±0.0 ^a	0.7±0.0 ^b	71.8 ^b	
	4	0.7±0.0 ^a	ND	24.8±1.3 ^a	ND	3.7±0.1 ^a	51.8±0.4 ^{ab}	14.6±0.4 ^{ab}	3.4±0.4 ^{ab}	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	70.4 ^a	
	5	0.7±0.0 ^a	ND	25.2±0.6 ^a	0.4±0.3 ^a	3.5±0.3 ^a	51.7±0.6 ^{ab}	14.3±0.2 ^a	3.3±0.1 ^a	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	0.5±0.0 ^a	0.6±0.0 ^a	0.6±0.0 ^a	70.3 ^a	

Each value in the table represents the mean of four measurements.

^{a-d} Means within each column for each treatment with different superscripts are significantly (P<0.05) different.

* RBD palm olein (A), sesame oil (B), Canola oil (C), RBD palm olein/ sesame oil (AB), RBD palm olein/canola oil (AC).

^e Mean of four analyses from two replications.

Table 1(cont...).Changes in fatty acids composition (g/ 100 g oil) during deep fat frying

Oil	Day	Fatty Acid Composition ^e													Total Unsaturation
		C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C18:2/C16:0			
BC*	0	ND	ND	7.4±0.3 ^{bc}	ND	4.3±0.2 ^d	51.2±1.7 ^b	31.9±2.0 ^a	4.0±0.3 ^a	0.6±0.0 ^c	0.6±0.1 ^{ab}	4.3±0.1 ^d	87.7±0.1 ^c		
	1	ND	ND	7.2±0.2 ^{cd}	ND	4.6±0.0 ^e	53.3±0.5 ^a	29.6±0.5 ^b	4.2±0.3 ^a	0.7±0.0 ^{bc}	0.6±0.0 ^{ab}	4.1±0.1 ^{cd}	87.7±0.3 ^{bc}		
	2	ND	ND	7.0±0.1 ^d	ND	4.6±0.1 ^{bc}	53.3±0.1 ^a	29.5±0.3 ^b	4.2±0.1 ^a	0.7±0.0 ^{ab}	0.7±0.0 ^{ab}	4.2±0.1 ^{cd}	87.7±0.2 ^c		
	3	ND	ND	7.3±0.1 ^{bcd}	ND	4.8±0.0 ^{ab}	53.5±0.2 ^a	29.0±0.3 ^b	4.1±0.0 ^a	0.7±0.0 ^{ab}	0.7±0.0 ^{ab}	4.0±0.1 ^{bc}	87.3±0.1 ^{bc}		
	4	ND	ND	7.5±0.1 ^b	ND	4.8±0.1 ^a	53.5±0.2 ^a	28.6±0.4 ^b	4.1±0.0 ^a	0.7±0.0 ^a	0.7±0.1 ^a	3.8±0.0 ^b	87.1±0.1 ^{ab}		
ABC*	0	0.4±0.0 ^c	ND	18.6±0.2 ^{bc}	0.2±0.0 ^a	4.3±0.1 ^d	49.2±0.4 ^b	23.1±0.2 ^a	2.8±0.1 ^a	0.6±0.1 ^a	0.5±0.0 ^a	1.3±0.0 ^b	75.8±0.3 ^{bc}		
	1	0.4±0.0 ^c	ND	18.6±0.6 ^{bc}	ND	4.5±0.0 ^e	50.3±0.5 ^a	23.1±0.2 ^a	2.6±0.1 ^{ab}	0.6±0.0 ^a	ND	1.2±0.0 ^b	76.0±0.4 ^c		
	2	0.4±0.0 ^{bc}	ND	18.6±0.1 ^c	0.2±0.0 ^a	4.5±0.1 ^{bc}	49.7±0.6 ^{ab}	22.9±0.2 ^a	2.7±0.1 ^{ab}	0.6±0.0 ^a	0.5±0.0 ^a	1.2±0.0 ^b	75.8±0.5 ^{bc}		
	3	0.5±0.0 ^{ab}	ND	19.3±0.2 ^{bc}	ND	4.6±0.1 ^{abc}	49.8±0.3 ^{ab}	22.3±0.4 ^b	2.6±0.3 ^{ab}	0.6±0.0 ^a	0.5±0.0 ^a	1.2±0.0 ^{ab}	75.2±0.1 ^{ab}		
	4	0.5±0.0 ^a	ND	19.6±0.5 ^{ab}	ND	4.7±0.1 ^{ab}	49.7±0.8 ^{ab}	21.9±0.1 ^b	2.6±0.2 ^{ab}	0.6±0.1 ^a	0.5±0.0 ^a	1.1±0.0 ^a	74.7±0.4 ^{ab}		
5	0.5±0.1 ^a	ND	19.9±1.2 ^a	ND	4.7±0.2 ^a	49.9±0.2 ^{ab}	21.3±0.4 ^c	2.4±0.2 ^b	0.6±0.0 ^a	0.5±0.1 ^a	1.1±0.1 ^a	74.1±0.8 ^a			

Each value in the table represents the mean of four measurements.
^{a-d} Means within each column for each treatment with different superscripts are significantly (P<0.05) different.
 * Sesame oil/canola oil (BC), RBD palm olein/sesame oil/canola oil (ABC).
^e Mean of four analyses from two replications.

Table 2. Changes in IV^c (g I₂/ 100 g oil) during five consecutive days of frying

Day	Type of oils					
	A*	C*	AB*	AC*	BC*	ABC*
0	57.27±0.35 _F ^a	101.36±0.32 _F ^e	78.62±0.29 _F ^c	77.97±0.23 _F ^b	101.42±0.14 _F ^e	88.8±0.38 _F ^d
1	56.04±0.33 _E ^a	100.65±0.27 _E ^f	77.02±0.46 _E ^c	76.46±0.46 _E ^b	99.73±0.21 _E ^e	87.43±0.34 _E ^d
2	55.66±0.29 _D ^a	99.01±0.27 _D ^e	76.06±0.29 _D ^c	75.44±0.27 _D ^b	99.14±0.10 _D ^e	86.33±0.30 _D ^d
3	54.56±0.31 _C ^a	98.08±0.33 _C ^e	75.22±0.23 _C ^c	74.7±0.20 _C ^b	98.2±0.24 _C ^e	85.07±0.25 _C ^d
4	53.01±0.21 _B ^a	95.63±0.34 _B ^e	74.51±0.42 _B ^c	74.08±0.05 _B ^b	97.26±0.29 _B ^f	84.22±0.22 _B ^d
5	52.81±1.05 _A ^a	94.1±0.34 _A ^d	73.77±0.18 _A ^b	73.64±0.29 _A ^b	96.17±0.11 _A ^e	83.61±0.19 _A ^c

Each value in the table represents the mean of four measurements.

^{a-d} Means within each row with different superscripts are significantly ($P < 0.05$) different.

^{A-F} Means within each column with different subscripts are significantly ($P < 0.05$) different.

* RBD palm olein (A), sesame oil (B), Canola oil (C), RBD palm olein/sesame oil (AB), RBD palm olein/canola oil (AC), sesame oil/canola oil (BC), RBD palm olein/sesame oil/canola oil (ABC).

^c Mean of four analyses from two replications.

amount of PUFAs in the oil BC, the lowest reduction in the amount of PUFAs was observed in the BC oil during the frying process. This observation also reveals that blending oil can improve the stability of single oils during the frying process.

Changes in iodine value (IV)

The changes in the IV of all frying media during five consecutive days of frying are shown in Table 2. The changes in the IV over the five days of frying were 4.46, 7.26, 4.86, 4.33, 5.25, and 5.19 (g I₂/100 g oil) for the frying media A, C, AB, AC, BC, and ABC, respectively (Table 2). The IV is a measure of the degree of unsaturation that is widely used to characterize fats and oils. The IV is expressed in terms of a percentage of the absorbed iodine. A decrease in the IV is consistent with the decrease in double bonds as an oil becomes oxidized. As shown in Table 2, the highest significant ($p < 0.05$) change in the IV was shown by the frying medium C, thus indicating that the highest decrease in double bonds occurred due to oxidative rancidity in the proposed frying media. This observation could be due to the presence of a high amount of PUFAs in frying medium C (30.0 g/100 g) (i.e., canola oil). The greater the unsaturation (or high IV), the more rapid the oil tends to be oxidized, particularly during deep-fat frying. Although the highest amount of PUFAs was observed in frying medium BC (35.9 g/100 g), the protective role of the natural antioxidants induced by the presence of sesame oil (i.e., sesamol, sesamin, and sesamol) resulted in a smaller decrease in the double bonds (Kim and Choe 2004).

Among all of the frying media, the treatments

A and AC showed the least significant ($p < 0.05$) changes in the IV, thus indicating that less oxidative rancidity occurred in these two frying media. This observation could be explained by the presence of a high level of saturated fatty acid (e.g., palmitic acid) in the RBD palm olein (Table 1). The present results are in agreement with those reported in a previous study (Kun, 1990). This study showed that adding oil A to oil C led to the changes in the IV of oil C, which acquired a moderate IV during the five consecutive days of frying.

Conclusion

The results of this study indicate that frying medium C was the least stable frying oil among the studied frying media in terms of the ratio of C18:2/C16:0 because it contains a high amount of polyunsaturated fatty acids. The stabilities of the other frying media are as follows (by order of the increase in the stability): BC, A, AB, ABC, and AC. This finding demonstrates that oil blending can improve the stability of a single frying oil against deterioration during deep-fat frying. In term of changes in the IV during deep-fat frying, AC was the most stable frying medium due to the lowest reduction (4.33 g I₂/100 g oil) in the IV, followed by A, AB, ABC, BC, and C. Of all of the oils used, the oil AC had the best stability in the deep-fat frying. Overall, oil C had the least stability against lipid oxidation; therefore, the formulation of oil C is not a good choice for deep-fat frying, and blended oils are the best choice in terms of deep-fat frying.

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