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Effect of Vegetable-Based Oil Blends on Physicochemical Properties of Oils During Deep-Fat Frying

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Abstract: Frying performance of palm olein, sesame oil and canola oil and their blends was investigated by assessing the physicochemical changes (i.e., color, viscosity, Free Fatty Acid (FFA), Peroxide Value (PV), Anisidine Value (AV), TOTOX Value (TV), Polymer Content (PC) and specific extinction) of oils during deep-fat frying of potato chips. Six frying oils, namely refined, bleached and 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) were considered as the independent variables. The physicochemical properties of the frying oils were significantly ($p<0.05$) influenced by the type and concentration of the component oil(s). Among all six frying oils, canola oil (C) generally exhibited the least chemical stability during the frying process and RBD palm olein (A) the highest.

Key words: Deep-fat frying, physicochemical properties, palm olein, canola oil, sesame oil

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INTRODUCTION

Deep-fat frying is one of the oldest and most popular food preparation methods. As reported by Garayo and Moreira (2002), the economy of commercial deep fat frying has been estimated to be \$6 billion year^{-1} in the United States and at least twice that amount for the rest of the world. Fried foods have a desirable flavor, color and crispy texture, which make deep-fat fried foods very popular with consumers (Boskou *et al*., 2006). Deep-fat frying is a process of immersing food in hot oil with a contact among oil, air and food at a high temperature of 150 to 190°C (Yamsaengsung and Moreira, 2002). The simultaneous heat and mass transfer of oil, food and air during deep-fat frying produces the desirable quality of fried foods.

In the presence of oxygen, moisture, trace elements and free radicals, physiochemical reactions such as thermoxidation, hydrolysis, polymerization, isomerization or cyclization take place at the high temperatures of the frying process, thus leading to the decomposition of frying oil and formation of monomeric, polymeric, primary and secondary oxidative compounds, thereby affecting the quality of oil and fried product (Andrikopoulos *et al*., 2002). The oxidized products of fatty acids give off-flavors and odors (hydrolytic rancidity) to the frying medium and fried foods (Lin *et al*., 2001).

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The reactions in deep-fat frying depend on factors such as replacement with fresh oil, frying conditions, original quality of frying oil, food materials, type of fryer, type and concentration of antioxidants and oxygen concentration (Sanchez-Muniz *et al*., 1992). Other factors such as frying temperature, quantity of frying, initial content of free fatty acids, polyvalent metals and unsaturated fatty acid content of the oil also affect the oxidative stability and overall quality of oil during the frying process (Melton *et al*., 1994). The physicochemical changes occurring during the frying process and the compounds formed in deteriorated frying oil have been extensively studied by previous researchers (Andrikopoulos *et al*., 2002). In general, deep-fat frying increases foaming, color, viscosity, density, the amount of polymeric and polar compounds and the free fatty acid content of frying oils.

According to Kun (1990), blending RBD palm olein and vegetable oil is done to reduce the content of linoleic and linolenic acids to a level where the effect is similar to partial hydrogenation without concerns about the formation of trans free fatty acid isomers. Refined, Bleached and Deodorized Palm Olein (RBDPO) is used extensively in frying processes (Man and Jaswir, 2000). The importance of selecting RBD palm olein, sesame oil and canola oil in this study based on the saturated Fatty Acid (FA) content of RBD palm olein, the oleic acid in canola oil and high natural antioxidant content in sesame oil, such as sesamin and sesamolin, which is supported by Fukuda *et al*. (1986). The main objective of the present study was to investigate the effect of blending vegetable-based oils during deep-fat frying by assessing Free Fatty Acid (FFA), Peroxide Value (PV), Anisidine Value (AV), Polymer Content (PC), color and viscosity of the oils.

MATERIALS AND METHODS

This study was conducted at the Faculty of Food Science and Technology, Universiti Putra Malaysia. The frying experiments was conducted from April to June 2008. All the physicochemical analysis were performed within 4 months (June to September 2008).

Materials

Refined, Bleached and Deodorized (RBD) palm olein, sesame oil, canola oil and potatoes (*Solanum tuberosum* L., var. Russet Burbank) were purchased from the local supermarket (Selangor, Malaysia). Petroleum-ether, 2-Propanol, Acetic acid glacial and 2,2,4-trimethylpentane were supplied by Fisher Scientific (Pittsburgh, PA, USA). All the other analytical and GC grade chemicals and solvents (Methanol, Diethylether, Chloroform) used were supplied by Merck (Darmstadt, Germany).

Preparation of Oil Blends

Three vegetable oils, namely Refined, Bleached and Deodorized (RBD) palm olein oil (A), sesame oil (B) and canola oil (C), were blended to prepare four different oil blends, i.e., RBD palm olein/sesame oil (1:1, w/w) (AB), RBD palm olein/canola oil (1:1, w/w) (AC), sesame oil/canola oil (1:1, w/w) (BC) and RBD palm olein/sesame oil/canola oil (1:1:1, w/w/w) (ABC).

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±1°C). They were then slightly blotted dry with tissue paper before weighing into 100 g batches for the frying process. In this study, 3.5 kg of frying oil (A, C, AB, AC, BC, or ABC) was put into a Jakad batch fryer

(ISD-306, Selangor, Malaysia). The temperature was then raised to 180±5°C over 20 min. The frying process started 20 min after the temperature reached 180±5°C. A batch of 100 g raw sliced potato was fried for 2.5 min at 180±5°C at 17.5 min intervals for a period of 3.5 h day^{-1} for five consecutive days. This is equivalent to ten times frying per day and therefore fifty times frying after five consecutive days. The fryer was left uncovered throughout the 3.5 h frying period. At the end of the tenth frying, the fryer was switched off. The lid of the fryer was then put on and the oil was allowed to cool overnight.

In this study, 120 g of oil samples were collected in amber bottles at 60°C for further analysis. All samples were stored under nitrogen at -20°C. Physicochemical analysis of oil was carried out immediately after the frying experiment. Fresh oil was not added to the frying vessel during the frying process.

Chemical Analysis

The PORIM test methods (PORIM Test Methods, 1995) were used to determine Free Fatty Acid (FFA), Peroxide Value (PV) and Anisidine Value (AV). The TOTOX (i.e., total oxidation products) Value (TV) was introduced for the evaluation of refined oils. TV is given as TV = 2PV + p-AV. The reason for the multiplication of the PV by a factor of 2 is that the PV has a more pronounced effect on the stability of refined oil than the AV. FFA was expressed as percent oleic acid for C, BC and ABC and percent palmitic acid for A, AB and AC.

Specific extinction was determined by means of a Shimadzo spectrophotometer (Shimadzo, UV mini 1240, Japan) at 233 and 269 nm ($E^{1\%}_{233}$ and $E^{1\%}_{269}$). Compounds showing an absorption maximum in the Ultraviolet (UV) region usually contain one or several conjugated double bonds. The position of the absorption maximum is shifted to higher wavelengths when the number of conjugated double bonds increases. The conjugated dienoic compounds, dissolved in isooctane, absorb UV radiation with a maximum at 233 nm (PORIM Test Methods, 1995). The conjugated trienoic system shows maximum absorbance at 269 nm (PORIM Test Methods, 1995).

Polymer Content

Polymer Content (PC) was determined according to the method described by Peled *et al.* (1975). Polymer content was measured to determine the portion of oil that, after methanolysis, remained insoluble in methanol at 25°C. Subsequently, 250 mL methanol was added to a 500 mL conical flask containing 1% sulphuric acid and 2 g of a heated oil. The conical flask was placed on a hot-plate magnetic stirrer; the methanol-oil mixture was boiled under a reflux condenser for 2 h and cooled to 25°C. The methanolic miscella was thoroughly decanted off and the methanol-insoluble fraction was washed with 15 mL of methanol. The insoluble portion was dissolved in 40 mL petroleum ether (60-80°C) and then transferred to a pre-weighed flask. The solvent was initially evaporated by a rotary vacuum evaporator (NEB1001, Japan) and then by placing the flask in a vacuum oven for 2 h at 140±5°C. The weight of the polymers was then recorded.

Color and Apparent Viscosity Measurement

Color and viscosity are the most commonly used physical parameters to evaluate the extent of frying oil deterioration in commercial and household frying experiments. Oil color was measured in a 1 inch cell by using a Lovibond[7] Tintometer (Salisbury, UK) according to the PORIM Test Methods (PORIM Test Methods, 1995) and viscosity was monitored by using a Haake Rheostress (RS 600, Germany). A Thermo-Haake RS600 Rheometer (Germany) was used with a plate sensor (C35/2Ti) to determine the viscosity of the frying oils. Applied shear rate was altered between 10 and 40 sec^{-1} during 60 sec. The gap between the plates was 0.105 mm an electric field was created in the fluid perpendicular to the plates and the rotor was forced to rotate. The voltage used in ER experiments was supplied by a 0B12.5 kV (in 0.5 kV increments) FUG (Germany) DC external electric field generator, which enabled resistivity to be created during the experiments. All the viscosity measurements were carried out at room temperature (25±1°C).

Total Polar Compounds (TPC)

The AOCS method Cd 20-91 was used for determining the Total Polar Compounds (TPC). A chromatographic column (21 mm i.d., 450 mm long with stopcock and ground glass joint) was filled with about 30 mL of a mixture of light petroleum and diethyl ether (87:13, v/v). A wad of glass wool was introduced at the lower end of the column with the aid of a glass rod. A slurry of 24 g of silica gel in about 80 mL of the solvent mixture was poured into the column. The elution solvent was drained through the column until its level was 10 cm above the silica gel level. About 4 g of sea sand, was added and the supernatant was drained down to the sand layer. For the determination of TPC, 2.5 g of the oil sample was dissolved in 20 mL of the solvent mixture containing light petroleum and diethyl ether (87:13, v/v) at room temperature (30±2 1°C), with slight warming, if necessary. The volume was then made up to 50 mL with the solvent mixture and 20 mL of resulting solution was introduced into the column and drained off to the level of the sand layer. The non-polar compounds were eluted with 150 mL of the solvent mixture at a flow rate of 2.5 mL min^{-1}. TPM was calculated as:

$$TPC\ (\%) = [m-m_1]\ 100$$

where, m_1 is the mass (g) of the non-polar fraction and m is the mass (g) of the sample contained in 20 mL of the solution added to the column.

Statistical Analysis

The data obtained from the experimental measurements was subjected to one way Analysis of Variance (ANOVA) to determine the significant differences among the treatments defined at $p<0.05$. The physicochemical properties of frying oil, namely free fatty acids, apparent viscosity, color, AV, PV, TPC and PC were considered as the response variables in this study. All the experiments and/or measurements were carried out in duplicate and reported as the Mean±SD of independent trials. Significant differences ($p<0.05$) between means were further determined by Duncan's multiple-range test. The data analysis was performed using SPSS Version 15.0 (SPSS Inc., USA). Regression analysis was done by using SPSS Version 15.0 (SPSS Inc., USA).

RESULTS AND DISCUSSION

Changes in Peroxide Value (PV)

The changes in PV during frying are presented in Table 1. The PV increased during the first few days of frying and then decreased during the last few days of frying (Table 1). Almost, the same pattern changes were reported in a previous deep-fat frying study (Che Man *et al*., 2005). This observation could be explained by the fact that peroxides are unstable compounds and will break down to carbonyl and aldehyde compounds during deep fat frying in the presence of high temperature, air and light (Perkins, 1967).

Table 1: Changes in physicochemical properties during five consecutive days of frying

		Type of oils					
Analysis	Day	A	C	AB	AC	BC	ABC
Peroxide value (mg kg^{-1})	0	0.71 ± 0.22^{bA}	0.82 ± 0.15^{bA}	0.45 ± 0.05^{aA}	1.37 ± 0.05^{dA}	1.14 ± 0.10^{cA}	0.69 ± 0.18^{bA}
	1	5.82 ± 0.29^{cB}	12.43 ± 0.19^{eD}	2.95 ± 0.13^{aBC}	10.48 ± 0.33^{dE}	2.89 ± 0.24^{aB}	5.31 ± 0.39^{bCD}
	2	8.06 ± 0.66^{dC}	10.53 ± 0.99^{eC}	2.59 ± 0.08^{aB}	6.46 ± 0.31^{cB}	3.91 ± 0.17^{bBC}	4.04 ± 0.06^{bB}
	3	9.28 ± 0.08^{eD}	8.38 ± 0.22^{dB}	3.17 ± 0.21^{aC}	8.11 ± 0.33^{dC}	3.96 ± 0.33^{bBC}	6.06 ± 0.66^{cE}
	4	11.15 ± 1.22^{cF}	8.08 ± 0.43^{bB}	3.84 ± 0.13^{aD}	8.81 ± 0.65^{bD}	4.52 ± 1.65^{aC}	5.09 ± 0.71^{aC}
	5	10.85 ± 0.79^{cE}	10.23 ± 0.59^{cC}	4.16 ± 0.66^{aD}	11.74 ± 0.36^{dF}	4.86 ± 0.09^{aC}	5.88 ± 0.14^{bDE}
ρ-Anisidine value	0	6.77 ± 1.08^{abA}	5.92 ± 1.02^{aA}	13.50 ± 1.04^{cA}	8.03 ± 1.04^{bA}	13.38 ± 1.64^{cA}	12.56 ± 0.84^{cA}
	1	43.31 ± 0.98^{aB}	65.02 ± 2.32^{eB}	58.95 ± 1.83^{cB}	53.40 ± 0.85^{bB}	61.22 ± 1.30^{dB}	62.36 ± 1.23^{dB}
	2	68.05 ± 1.26^{aC}	104.76 ± 1.28^{eC}	75.77 ± 0.91^{bC}	93.69 ± 0.31^{dC}	90.79 ± 1.48^{cC}	91.79 ± 0.98^{cC}
	3	79.83 ± 2.12^{aD}	140.73 ± 2.21^{fD}	108.73 ± 1.43^{bD}	126.89 ± 1.41^{eD}	122.97 ± 2.62^{dD}	117.71 ± 1.65^{cD}
	4	98.91 ± 1.48^{aE}	182.50 ± 1.24^{dE}	141.87 ± 2.30^{bE}	143.01 ± 1.39^{bcE}	145.66 ± 1.75^{cE}	144.72 ± 1.91^{cE}
	5	104.01 ± 2.56^{aF}	199.42 ± 1.86^{eF}	171.40 ± 3.26^{cF}	165.52 ± 1.11^{bF}	185.25 ± 2.42^{dF}	168.84 ± 0.71^{cF}
TOTOX value	0	8.20 ± 1.45^{aA}	7.55 ± 0.81^{aA}	14.39 ± 1.07^{cA}	10.77 ± 0.98^{bA}	15.65 ± 1.45^{cA}	13.95 ± 0.49^{cA}
	1	54.95 ± 0.81^{aB}	89.88 ± 2.16^{dB}	64.84 ± 1.60^{bB}	74.36 ± 1.42^{cB}	67.00 ± 1.68^{bB}	72.97 ± 1.68^{cB}
	2	84.17 ± 2.44^{bC}	125.81 ± 1.39^{eC}	80.96 ± 1.07^{aC}	106.61 ± 0.64^{dC}	98.62 ± 1.37^{cC}	99.86 ± 1.10^{cC}
	3	98.39 ± 2.18^{aD}	157.48 ± 2.35^{eD}	115.07 ± 1.58^{bD}	143.10 ± 1.84^{dD}	130.90 ± 2.05^{cD}	129.83 ± 1.73^{cD}
	4	121.21 ± 1.31^{aE}	198.66 ± 1.86^{eE}	149.55 ± 2.43^{bE}	160.62 ± 2.20^{dE}	154.69 ± 3.05^{cE}	154.89 ± 1.97^{cE}
	5	125.71 ± 1.57^{aF}	219.88 ± 1.65^{eF}	179.72 ± 3.84^{bF}	189.00 ± 1.39^{cF}	194.97 ± 2.48^{dF}	180.60 ± 0.60^{bF}
$E^{1\%}{}_{1cm}$ at 233 nm	0	0.04 ± 0.01^{aA}	0.05 ± 0.01^{abA}	0.05 ± 0.01^{aA}	0.04 ± 0.01^{aA}	0.06 ± 0.01^{bA}	0.06 ± 0.01^{abA}
	1	0.10 ± 0.05^{abA}	0.13 ± 0.05^{bcdB}	0.11 ± 0.05^{abcB}	0.16 ± 0.03^{cdB}	0.18 ± 0.02^{dB}	0.06 ± 0.01^{aA}
	2	0.12 ± 0.07^{abA}	0.19 ± 0.03^{cC}	0.16 ± 0.05^{bcB}	0.20 ± 0.04^{cBC}	0.21 ± 0.02^{cC}	0.09 ± 0.03^{aA}
	3	0.12 ± 0.06^{aA}	0.22 ± 0.03^{bC}	0.21 ± 0.02^{bC}	0.23 ± 0.04^{bC}	0.23 ± 0.01^{bCD}	0.12 ± 0.02^{aB}
	4	0.12 ± 0.06^{aA}	0.24 ± 0.02^{bC}	0.24 ± 0.03^{bC}	0.25 ± 0.05^{bC}	0.25 ± 0.01^{bDE}	0.14 ± 0.02^{aB}
	5	0.13 ± 0.07^{aA}	0.24 ± 0.02^{bC}	0.23 ± 0.04^{bC}	0.25 ± 0.04^{bC}	0.26 ± 0.02^{bE}	0.16 ± 0.04^{aB}
$E^{1\%}{}_{1cm}$ at 269 nm	0	0.20 ± 0.00^{bA}	0.14 ± 0.00^{aA}	0.23 ± 0.01^{bA}	0.15 ± 0.01^{aA}	0.20 ± 0.02^{bA}	0.20 ± 0.03^{bA}
	1	0.24 ± 0.01^{aB}	0.22 ± 0.01^{aB}	0.40 ± 0.02^{bcB}	0.24 ± 0.06^{aB}	0.46 ± 0.03^{cB}	0.37 ± 0.06^{bB}
	2	0.27 ± 0.01^{aC}	0.24 ± 0.01^{aB}	0.60 ± 0.08^{cC}	0.42 ± 0.03^{bD}	0.66 ± 0.04^{cC}	0.60 ± 0.04^{cC}
	3	0.32 ± 0.01^{aD}	0.38 ± 0.01^{bC}	0.72 ± 0.02^{cD}	0.37 ± 0.02^{bC}	0.78 ± 0.03^{dD}	0.69 ± 0.04^{cD}
	4	0.37 ± 0.01^{aE}	0.48 ± 0.03^{bD}	0.90 ± 0.07^{dE}	0.40 ± 0.03^{aCD}	0.90 ± 0.04^{dE}	0.84 ± 0.01^{cE}
	5	0.32 ± 0.01^{aD}	0.57 ± 0.02^{cE}	0.93 ± 0.03^{dE}	0.48 ± 0.02^{bE}	0.98 ± 0.06^{dF}	0.94 ± 0.03^{dF}
Viscosity (mPa.s)	0	68.44 ± 0.73^{dA}	59.88 ± 0.30^{abA}	61.63 ± 0.27^{cA}	61.70 ± 0.49^{cA}	60.90 ± 0.85^{bcA}	59.38 ± 1.41^{aA}
	1	72.31 ± 1.17^{dB}	63.77 ± 0.28^{aB}	66.53 ± 1.12^{bB}	68.51 ± 1.27^{cB}	62.58 ± 0.78^{aB}	$66.32\pm0.34^{b}{}_{C}$
	2	74.56 ± 0.93^{dC}	68.37 ± 0.47^{bC}	69.99 ± 0.16^{cC}	69.71 ± 1.26^{cB}	64.11 ± 0.56^{aC}	64.00 ± 0.57^{aB}
	3	77.42 ± 1.15^{dD}	72.02 ± 0.47^{bD}	72.76 ± 0.18^{bD}	74.80 ± 0.15^{cC}	67.84 ± 0.70^{aD}	68.56 ± 0.80^{aD}
	4	84.06 ± 0.59^{dE}	77.89 ± 0.25^{cE}	76.11 ± 0.30^{bE}	77.09 ± 0.77^{cD}	71.20 ± 0.76^{aE}	71.43 ± 0.72^{aE}
	5	89.51 ± 0.71^{eF}	84.10 ± 0.45^{dF}	80.73 ± 0.27^{cF}	81.65 ± 1.22^{cE}	74.75 ± 0.48^{aF}	76.75 ± 0.31^{bF}
Polar content (%)	0	8.50 ± 0.74^{cA}	6.94 ± 0.56^{bA}	9.94 ± 0.27^{dA}	8.18 ± 0.74^{cA}	6.00 ± 0.18^{aA}	10.63 ± 0.78^{dA}
	3	20.10 ± 0.65^{cB}	20.20 ± 1.01^{cB}	16.93 ± 0.64^{bB}	16.01 ± 0.30^{abB}	15.18 ± 1.16^{aB}	15.48 ± 1.00^{aB}
	5	25.43 ± 0.53^{bC}	26.78 ± 0.90^{cC}	24.33 ± 1.03^{bC}	24.80 ± 0.73^{bC}	21.75 ± 1.31^{aC}	22.95 ± 0.48^{aC}
Polymer content (%)	0	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}
	3	0.96 ± 0.20^{aB}	1.03 ± 0.30^{abB}	0.97 ± 0.11^{aB}	1.01 ± 0.17^{abB}	1.27 ± 0.18^{abB}	1.02 ± 0.15^{abB}
	5	1.51 ± 0.26^{aC}	2.02 ± 0.23^{bcC}	1.63 ± 0.17^{aC}	1.87 ± 0.22^{abC}	2.19 ± 0.16^{bcC}	1.98 ± 0.17^{bC}

Each value in the table represents the mean of four measurements. A: Refined, bleached and deodorized (RBD) palm olein oil; C: Canola oil; AB: RBD palm olein/sesame oil (1:1, w/w); AC: RBD palm olein/canola oil (1:1, w/w); BC: Sesame/canola oil (1:1, w/w); ABC: RBD palm olein/sesame oil/canola oil (1:1:1, w/w/w). For each frying day, means within each rows with same superscripted letters$^{a\text{-}f}$ are not significantly different at p = 0.05. For each quality parameter, means within each column with same superscripted letters$^{A\text{-}F}$ are not significantly different at p = 0.05

A significant difference was observed ($p<0.05$) among the PVs of all the treatments. The results showed that there was an initial sharp increase in PV from day 0 to 1 in all frying oils, while, the rate became slower after first day of frying. The highest and least alterations in PV were shown by treatments C and BC, respectively (Table 1). The results indicated that the PV of frying medium C decreased after first day of frying until the end of the fourth day and then increased on the last day of frying. Conversely, the PV of frying medium A increased continuously from the first through fourth day of frying, while it decreased at the end of the frying process (Table 1). As shown in Table 1, the PV of frying medium AB decreased from the first day to the end of the second day of frying, while it increased slightly from the third day until the end of the frying operation. Initially, a sharp increase in the PV of frying medium AC was observed and it increased until the end of the frying process. The results showed a slight increase in PV of treatment BC (Table 1) during the entire five days of frying. Treatment ABC shows a fluctuation in PV from the first to second day of frying, while it decreased from third to fourth day of frying. The results also showed that the PV of ABC increased from the second day to third day and from the fourth day to fifth day of frying operation (Table 1).

Since, high temperature (180±5°C) was applied for the frying process, peroxides formed during oxidation might be decomposed to secondary oxidation products, as also reported in a previous study (Robards *et al*., 1988). Lipid hydroperoxides may be partially polymerized during the reaction, thus leading to the formation of less reactive products. In general, the results indicated that the highest change in PV was observed in treatment BC, whereas the least change was shown by AB formula (Table 1). This could be due to the presence of natural antioxidants such as sesamin and sesamolin in sesame oil. At the end of five consecutive frying days, the PV were found to be 10.85, 10.23, 4.16, 11.74, 4.86 and 5.88 for A, C, AB, AC, BC and ABC, respectively (Table 1). These findings indicate that the characteristics of a single oil regarding stability against primary oxidation may be improved by blending.

Changes in Anisidine Value (AV)

The changes in the p-AV of the frying oils during the 5 day frying process are shown in Table 1. An increase in the p-AV of all frying oils was observed with prolonging the frying time. This finding could be explained by the fact that the less stable primary oxidative compounds (i.e., hydroperoxides) decompose further to form aldehydic compounds. Aldehyde compounds are secondary oxidation products formed during the oxidative rancidity of lipids. Aldehyde compounds account for almost 50% of volatile compounds formed during lipid oxidation of vegetable oils such as soybean oil (Przybylski and Eskin, 1995). The highest and least significant ($p<0.05$) changes in p-AV were observed in frying mediums C and A, respectively (Table 1). These results confirmed that frying medium C (canola oil) was found to be more susceptible to oxidation at high frying temperature than the other frying oils. This observation could be due to the presence of a high concentration of polyunsaturated fatty acids in canola oil compared to the other frying oils. At the end of the frying process, the p-AV were found to be 104.01, 199.42, 171.40, 165.52, 185.25 and 168.84 for A, C, AB, AC, BC and ABC, respectively (Table 1). By blending, either of two other oils with oil C, the p-AV decreased within a 5-day frying period compared with oil C alone.

Determination of TOTOX Value (TV)

TV is a measure of total oxidation, including primary and secondary products. The results obtained from TV determination are shown in Table 1. After the fifth day of frying, the TVS of the frying oils were found to be 117.51, 212.33, 165.33, 178.23, 179.32 and 166.65 for A, C, AB, AC, BC and ABC, respectively. In all treatments, TV increased during the frying process. As shown in Table 1, the highest and lowest TVS were seen in frying mediums C and A, respectively, thus indicating the highest (A) and lowest (C) stability of frying oil to oxidative rancidity. This observation could be explained by the high and low concentration of polyunsaturated fatty acids present in frying mediums A and C, respectively (Table 1). Although, frying medium BC had the highest amounts of polyunsaturated fatty acids, the protective role of natural antioxidants present in sesame oil may protect this frying medium from drastic oxidation as compared to frying medium C (Table 1). Findings in Table 1 indicated TV decreased by adding other oils to oil C, compared to oil C alone. Thus, the frying oil containing higher content of linolenic acid was shown to be less stable to oil deterioration during deep-frying than regular oils were. This observation is in agreement with that reported in a previous study (Abdulkarim *et al.*, 2007).

Changes in Total Polar Compounds (TPC)

The changes in the TPC content of all the treatments during the frying process are shown in Table 1. The results indicated that TPC significantly increased ($p<0.05$) with prolonged frying time for all the frying oils. The enhanced rates of TPC were found to be 12.32, 14.39, 15.75, 16.62, 16.93 and 19.84% for ABC, AB, BC, AC, A and C, respectively (Table 1) which indicated that the stability of oils against oxidative changes was improved by blending. As shown by the results, the oils containing higher percentages of unsaturated fatty acids provided more polar compounds compared to the more saturated ones. However, the absolute degree of unsaturation determined by the IV (data not shown) was not directly proportional to the amount of polar compounds formed during the frying process. The highest ($p<0.05$) TPC content was shown by the frying medium C, while frying medium ABC showed the lowest level of TPC at the end of the frying process (Table 1). This observation indicated the high stability of the frying oil ABC to the changes in TAG that occurred during the frying experiment.

Determination of TPC is mainly carried out as the most accurate method for assessing the degree of frying oil degradation (Blumenthal, 1996). The concentration level of polar compounds is a good indicator of the overall quality of frying oils, providing critical information about the total amount of newly formed compounds having higher polarity than triacylglycerols. Many European countries such as Spain, Portugal, France, Germany, Belgium, Switzerland, Italy and the Netherlands have established regulatory limits for TPC in frying oils (Blumenthal, 1996). Most of these countries have considered a limit of 25% TPC. In some other countries, the allowable content of Dimeric and Polymeric Triglycerides (DPTG) is 16% (Firestone *et al.*, 1991).

Changes in Free Fatty Acid Content (FFA)

The changes in FFA content during five consecutive days of the frying process are given in Table 2. There were significant differences ($p<0.05$) among the frying media in terms of FFA. During five consecutive days of frying, the FFA content of frying medium A, C, AB, AC, BC and ABC increased from 0.09, 0.05, 0.79, 0.05, 0.85 and 0.62% to 0.32, 0.22, 1.87, 0.21, 1.46 and 1.21%, respectively (Table 2). The increment of FFA contents observed among all the frying oils were in the order AB>BC>ABC>A>C>AC, which indicated that the most stable formulation in terms of FFA was obtained by blending oils A and C with each other. The released free fatty acids are more susceptible to thermal oxidation under elevated frying temperatures, thereby representing oil that is more unstable. Thus, the frying medium AB and AC showed the highest and least susceptibility to the hydrolysis of fatty acids, respectively.

During lipid oxidation, short-chain fatty acids are produced by secondary oxidation of unsaturated aldehydes and other products originating from the cleavage of lipid hydroperoxides, which are products of primary oxidation. Formic acid is present in particularly high amounts. More fatty acids may also be formed by the hydrolytic cleavage of triacylglycerols, an important marker of frying oil degradation. The presence of Free Fatty Acid (FFA) in frying oil was shown to catalyze further hydrolysis of triglycerides (Krishnamurthy, 1982). Generally, the FFA level does not correlate with fried food quality.

Table 2: Changes in free fatty acids (%) during deep fat frying

	Type of oils					
Day	A	C	AB	AC	BC	ABC
0	0.09±0.00^{aA}	0.05±0.02^{aA}	0.79±0.05^{cA}	0.05±0.01^{aA}	0.85±0.02^{dA}	0.62±0.05^{bA}
1	0.11±0.01^{bB}	0.07±0.00^{aB}	1.01±0.01^{eB}	0.08±0.01^{aB}	0.97±0.04^{dB}	0.67±0.00^{cB}
2	0.17±0.02^{bC}	0.11±0.01^{aC}	1.22±0.01^{eC}	0.11±0.01^{aC}	1.08±0.04^{dC}	0.82±0.02^{cC}
3	0.21±0.01^{bD}	0.16±0.01^{aD}	1.41±.03^{eD}	0.14±0.01^{aD}	1.25±0.06^{dD}	0.98±0.03^{cD}
4	0.25±0.01^{cE}	0.21±0.00^{bE}	1.63±0.02^{fE}	0.17±0.01^{aE}	1.39±0.01^{eE}	1.08±0.02^{dE}
5	0.32±0.01^{bF}	0.22±0.01^{aE}	1.87±0.08^{eF}	0.21±0.01^{aF}	1.46±0.01^{dF}	1.21±0.01^{cF}

Each value in the table represents the mean of four measurements. A: Refined, bleached and deodorized (RBD) palm olein oil; C: Canola oil; AB: RBD palm olein/sesame oil (1:1, w/w); AC: RBD palm olein/canola oil (1:1, w/w); BC: Sesame/canola oil (1:1, w/w); ABC, RBD palm olein/sesame oil/canola oil (1:1:1, w/w/w). For each frying day, means within each rows with same superscripted letters$^{a\text{-}f}$ are not significantly different at $p = 0.05$. For each quality parameter, means within each column with same superscripted letters$^{A\text{-}F}$ are not significantly different at $p = 0.05$

The increase in free fatty acid values during frying could be mainly due to the hydrolysis of the oils, although oxidative pathways can also result in the formation of free fatty acids. Sesame oil is known to be one of the most resistant oil to oxidative rancidity among the vegetable oils, due to the natural antioxidants such as sesamol and sesamin. The highest FFA content was shown by the frying medium containing higher sesame oil content (Table 2). This could be explained by the fact that the phenolic antioxidants act by inhibiting oxidation reactions without any direct effect on hydrolytic reactions (Coppen, 1989).

Changes in Polymer Content (PC)

The results showed that the PC of all the frying oils increased over the five days of the frying experiment (Table 1). The PCS of all the frying oils were significantly ($p<0.05$) different from each other. The frying medium A showed the lowest ($p<0.05$) polymer content compared to the other frying oils. It is well known that the PC increases as the oxidative rancidity of oil exposed to frying temperatures proceeds (Yoon *et al.*, 1985). The increase in PC is due to the formation of higher molecular weight substances by polymerization occurring at elevated frying temperature (Peled *et al.*, 1975). The oil containing a higher percentage of polyunsaturated fatty acids shows the greater tendency to form polymeric compounds rather than a highly saturated fatty acid-containing oil. The frying medium BC showed the highest level ($p<0.05$) of PC compared to the other frying oils (Table 1).

Changes in Specific Extinction ($E^{1\%}_{1cm}$ at 233 and 269 nm)

The changes in $E^{1\%}_{1cm}$ at 233 and 269 nm during five consecutive days of frying are shown in Table 1. The sharp change in the $E^{1\%}_{1cm}$ at 233 nm during the first two days of frying confirmed the formation of a large amount of conjugated dienes, while a negligible increase in the content of conjugated dienes was observed during the last three days of the frying process (Table 1). This could be explained by the equilibrium between the formation rate of conjugated dienes and the rate at which those compounds formed polymers (Peled *et al.*, 1975). This may be because both formation and decomposition of peroxides occurs during heating of oil at high frying temperatures. However, the amount of secondary oxidation products formed during the frying process increases constantly. Moreover, the data obtained from PC for the same periods of frying supported this assumption (Table 1). In this study, the frying medium A had the lowest level ($p<0.05$) of conjugated dienes compared to the other frying oils, followed by ABC, while the frying oils AC and BC showed higher levels in the $E^{1\%}_{1cm}$ absorption recorded at 233 nm, thus indicating higher amounts of conjugated dienes formed during frying (Table 1). This indicated that the lowest level of conjugated dienes was found in the blended oils.

Oxidation of polyunsaturated fatty acids is accompanied by increased ultraviolet absorption. In fact, the changes in ultraviolet absorption at 233 and 269 nm are associated with the changes in the conjugated dienes and trienes formed due to the oxidation of polyunsaturated fatty acids. The resulting conjugated dienes exhibit an intense absorption at 233 nm; similarly, the conjugated trienes absorb at 269 nm. Although, the magnitude of changes in $E^{1\%}_{1cm}$ is not readily related to the degree of oxidation, the changes in $E^{1\%}_{1cm}$ at 233 and 269 nm of a given substance can be used as a relative degree of oxidation (Gray, 1978). Unlike, the PV, $E^{1\%}_{1cm}$ at 233 nm indicates the degree of primary oxidation by showing an increase in diene content with prolonged frying time.

The $E^{1\%}_{1cm}$ absorption at 269 nm, which indicated the formation of conjugated trienes, significantly ($p<0.05$) increased during the five consecutive days of frying in all the frying oils (Table 1). At the end of the frying period, the changes in $E^{1\%}_{1cm}$ at 269 nm were 0.12, 0.43, 0.70, 0.33, 0.78 and 0.74 for frying oils A, C, AB, AC, BC and ABC, respectively, which indicates that blending oil A and C together decreases the changes in $E^{1\%}_{1cm}$ at 269 nm compared with oil C alone. The change in the $E^{1\%}_{1cm}$ at 268 nm was not in parallel with the change in $E^{1\%}_{1cm}$ at 233 nm. Like the dienes, the trienes could also form polymers during the frying process (Peled *et al*., 1975).

Changes in Color and Viscosity

Table 3 shows the changes in color for all frying oils (A, C, AB, AC, BC, ABC) for the five consecutive days of the frying process. Color change in frying oils is a visual indication of the extent of oil deterioration caused by oxidation. An increase in the color intensity is due to accumulation of non-volatile decomposed compounds such as oxidized triacylglycerols and FFA. As shown in Table 3, all the treatments darkened during the frying\trial, where the rate of darkening was directly proportional to the frying time. As illustrated by previous researchers (Che Man *et al*., 1996), the darkening of oils was partly due to the absorption of color from the fried food. Therefore, it is not accurate to evaluate the overall quality

Table 3: Changes in colour during deep fat frying

		Type of oils					
Colour	Day	A	C	AB	AC	BC	ABC
Red	0	1.70 ± 0.08^{bC}	0.25 ± 0.13^{aA}	10.00 ± 0.00^{cC}	0.65 ± 0.26^{aA}	10.75 ± 0.96^{cdC}	11.00 ± 1.15^{dB}
	1	1.38 ± 0.32^{aB}	0.68 ± 0.15^{aAB}	8.00 ± 0.82^{bB}	0.88 ± 0.21^{aAB}	10.25 ± 0.50^{cC}	10.25 ± 0.96^{cAB}
	2	1.28 ± 0.22^{aAB}	0.88 ± 0.21^{aAB}	7.25 ± 1.50^{bAB}	1.08 ± 0.10^{aAB}	8.25 ± 0.96^{bB}	10.00 ± 1.41^{cAB}
	3	1.15 ± 0.13^{aAB}	1.28 ± 0.22^{aB}	6.00 ± 1.15^{bAB}	1.18 ± 0.13^{aBC}	7.25 ± 1.26^{cAB}	9.75 ± 0.96^{dAB}
	4	1.10 ± 0.08^{aAB}	2.08 ± 0.36^{aC}	5.75 ± 1.50^{bA}	1.53 ± 0.32^{aCD}	7.25 ± 1.26^{bAB}	9.00 ± 1.63^{cAB}
	5	1.08 ± 0.10^{aA}	3.30 ± 0.95^{bD}	6.00 ± 1.83^{cAB}	1.78 ± 0.49^{abD}	6.25 ± 1.26^{cA}	8.75 ± 1.26^{dA}
Yellow	0	10.00 ± 0.00^{bA}	3.375 ± 1.25^{aA}	10.00 ± 0.00^{bA}	8.50 ± 1.91^{bA}	10.00 ± 0.00^{bA}	10.00 ± 0.00^{bA}
	1	10.13 ± 0.15^{bA}	6.75 ± 1.50^{aB}	10.75 ± 1.71^{bA}	10.00 ± 0.00^{bA}	10.00 ± 0.00^{bA}	10.00 ± 0.00^{bA}
	2	10.18 ± 0.21^{abA}	9.00 ± 1.15^{aBC}	11.00 ± 1.41^{bA}	10.25 ± 0.50^{abA}	10.50 ± 0.58^{bA}	10.25 ± 0.50^{abAB}
	3	10.08 ± 0.15^{aA}	10.10 ± 0.20^{aCD}	11.50 ± 1.29^{bA}	10.50 ± 1.00^{abA}	10.75 ± 0.96^{abA}	10.50 ± 0.58^{abABC}
	4	10.33 ± 0.38^{aAB}	12.50 ± 3.32^{aD}	12.00 ± 1.83^{aA}	13.25 ± 2.36^{aB}	10.75 ± 0.96^{aA}	11.00 ± 0.82^{aBC}
	5	10.55 ± 0.19^{aB}	18.75 ± 2.50^{cE}	12.50 ± 2.38^{aA}	15.75 ± 2.99^{bB}	11.00 ± 1.15^{aA}	11.25 ± 0.96^{aC}
Blue	0	ND	ND	3.50 ± 0.58^{abA}	ND	4.00 ± 1.15^{bA}	2.75 ± 0.96^{aA}
	1	ND	ND	10.00 ± 0.82^{cB}	ND	8.00 ± 1.41^{bB}	5.75 ± 0.50^{aB}
	2	ND	ND	10.50 ± 1.00^{bB}	ND	10.00 ± 0.82^{bC}	8.50 ± 1.29^{aC}
	3	ND	ND	10.75 ± 0.96^{bB}	ND	10.25 ± 0.50^{bC}	9.00 ± 1.15^{aC}
	4	ND	ND	11.00 ± 1.41^{bB}	ND	10.50 ± 0.58^{bC}	9.00 ± 1.15^{aC}
	5	ND	ND	11.75 ± 1.71^{bB}	ND	10.75 ± 0.96^{bC}	9.00 ± 1.15^{aC}

Each value in the table represents the mean of four measurements. A: Refined, bleached and deodorized (RBD) palm olein oil; C: Canola oil; AB: RBD palm olein/sesame oil (1:1, w/w); AC: RBD palm olein/canola oil (1:1, w/w); BC: Sesame/canola oil (1:1, w/w); ABC: RBD palm olein/sesame oil/canola oil (1:1:1, w/w/w). For each frying day, means within each rows with same superscripted letters$^{a\text{-}f}$ are not significantly different at $p = 0.05$. For each quality parameter, means within each column with same superscripted letters$^{A\text{-}F}$ are not significantly different at $p = 0.05$

of frying oils only by monitoring the color changes alone. As stated by Tan *et al.* (1985), the yellow color of RBD palm olein could be due to the presence of carotenoids and xanthophylls that could not be removed during the bleaching process. Che Man *et al.* (1999) suggested that the darkening of RBD palm olein cannot be solely related to oxidative oil deterioration.

The yellow color of frying oils significantly ($p<0.05$) increased throughout the five consecutive days of frying (Table 3), although there were not any significant ($p>0.05$) differences between treatments AB and BC during five consecutive days. In most cases, except for frying oils C and AC, the red color significantly ($p<0.05$) decreased during five days of the frying process. Blue color observed in three oil blends (AB, BC and ABC) significantly ($p<0.05$) increased throughout the five days frying process. The presence of blue color in frying oils AB, BC and ABC could be explained by the presence of sesame oil in these oil blends. The color of frying oil darkened during frying, most probably due to the oxidative reactions and consequently the formation of browning pigments from the potato chips (Peled *et al.*, 1975). Formation of polymers during the frying operation may also promote the darkening of oils.

The changes in viscosity during five consecutive days of frying are shown in Table 1. There was a notable increase in viscosity with increasing frying time (Table 1). The viscosity values after five days of frying were 21.07, 24.22, 19.10, 19.95, 13.85 and 17.37 mPa.s for frying oils A, C, AB, AC, BC and ABC, respectively. The increases in frying oil viscosity could be due to the formation of high molecular weight polymer compounds during polymerization (Gray, 1978). The treatment A had a consistently higher viscosity among the six frying oils during five days of frying. Oil C had the highest increase in viscosity during five days of frying, where this could be due to the high content of polyunsaturated FAs that polymerized during the frying period and this is supported by the PC values, because oil C had the second highest PC among all formulations. The order of the increasing in viscosity of other formulations was as follow:

$$A>AC>AB>ABC>BC$$

This shows the lowest increase in viscosity was with blended oils (BC) and also indicates that blending oils with oil C causes a moderation of the increase in viscosity of the oil during frying compared to C alone and finally that the best stability against an increase in viscosity during frying was seen in blended oils.

Correlation between Analytical Methods in each Formulation during Frying

The correlations of coefficients (r) between each pair of analytical methods for each frying medium were calculated to study the relationship between each pair of physicochemical characteristics and are shown in Table 4. In frying oil A, there was a significant correlation ($p<0.05$) between most pairs of physicochemical characteristics as shown in Table 4. The highest correlation was observed between TV and p-AV ($r = 1.000$). In frying oil C, most pair correlation analysis were significant ($p<0.05$) (Table 4). The highest correlations ($r = 1.000$) were between FFA and TPC, PC and viscosity, TPC and p-AV and TV and TPC. In frying oil AB, the majority of correlation analysis were significant ($p<0.05$). Among those, five showed a 100% correlation: TPC with viscosity and PC with FFA, p-AV, viscosity and TV. In treatment AC, most of the correlations between the studied factors were significant ($p<0.05$) with the exceptions shown in Table 4. The two highest correlations ($r = 1.000$) were measured between PC and FFA and Red color and TPC. In frying oil BC, the highest correlations ($r = 1.000$) were TV with p-AV and PC with TPC. Treatment ABC showed the highest correlations for viscosity with PC, PC with red color and TV with p-AV.

Table 4: Correlation between each pair of analytical methods in each formulation during deep-fat frying

Oils	Analysis	FFA	PV	ρ-AV	Visco.	TV	233 nm	269 nm	TPC	PC	Red
A	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.876	—	—	—	—	—	—	—	—	—
	ρ-AV	0.934	0.990	—	—	—	—	—	—	—	—
	Visco.	0.983	0.866	0.920	—	—	—	—	—	—	—
	TV	0.925	0.993	1.000	0.912	—	—	—	—	—	—
	233 nm	0.764	0.955	0.923	0.745*	0.930	—	—	—	—	—
	269 nm	0.847	0.934	0.936	0.837	0.937	0.796*	—	—	—	—
	TPC	0.983*	0.986*	0.997	0.957*	0.996*	0.978*	0.951*	—	—	—
	PC	0.992*	0.975*	0.992*	0.971*	0.990*	0.965*	0.933*	0.998	—	—
	Red	-0.877	-0.995	-0.985	-0.862	-0.988	-0.957	-0.923	-0.978*	-0.965*	—
C	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.319*	—	—	—	—	—	—	—	—	—
	ρ-AV	0.980	0.497*	—	—	—	—	—	—	—	—
	Visco.	0.978	0.393*	0.973	—	—	—	—	—	—	—
	TV	0.958	0.573*	0.996	0.959	—	—	—	—	—	—
	233 nm	0.918	0.589*	0.970	0.895	0.978	—	—	—	—	—
	269 nm	0.982	0.355*	0.964	0.987	0.947	0.875	—	—	—	—
	TPC	1.000	0.990*	1.000	0.982*	0.999	0.972*	0.992*	—	—	—
	PC	0.988*	0.947*	0.978*	1.000	0.975*	0.915*	0.998	0.984*	—	—
	Red	0.922	0.354*	0.907	0.977	0.893	0.789*	0.967	0.930*	0.981*	—
AB	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.887	—	—	—	—	—	—	—	—	—
	ρ-AV	0.996	0.921	—	—	—	—	—	—	—	—
	Visco.	0.998	0.908	0.996	—	—	—	—	—	—	—
	TV	0.994	0.927	1.000	0.995	—	—	—	—	—	—
	233 nm	0.947	0.904	0.953	0.947	0.954	—	—	—	—	—
	269 nm	0.983	0.896	0.981	0.980	0.981	0.986	—	—	—	—
	TPC	0.995*	0.961*	0.991*	0.994*	0.990*	0.905*	0.971*	—	—	—
	PC	1.000	0.988*	1.000	1.000	1.000	0.952*	0.993*	0.992*	—	—
	Red	-0.904	-0.932	-0.920	-0.912	-0.924	-0.986	-0.951	-0.858*	-0.915*	—
AC	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.711*	—	—	—	—	—	—	—	—	—
	ρ-AV	0.976	0.725*	—	—	—	—	—	—	—	—
	Visco.	0.986	0.803*	0.981	—	—	—	—	—	—	—
	TV	0.974	0.776*	0.997	0.988	—	—	—	—	—	—
	233 nm	0.882	0.803*	0.955	0.924	0.964	—	—	—	—	—
	269 nm	0.894	0.648*	0.935	0.882	0.928	0.916	—	—	—	—
	TPC	0.994*	0.979*	0.949*	0.978*	0.953*	0.891*	0.975*	—	—	—
	PC	1.000	0.992*	0.971*	0.991*	0.974*	0.925*	0.990*	0.997*	—	—
	Red	0.993	0.717*	0.957	0.973	0.957	0.866	0.886	1.000	0.997*	—
BC	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.918	—	—	—	—	—	—	—	—	—
	ρ-AV	0.987	0.951	—	—	—	—	—	—	—	—
	Visco.	0.983	0.857	0.972	—	—	—	—	—	—	—
	TV	0.986	0.955	1.000	0.969	—	—	—	—	—	—
	233 nm	0.889	0.989	0.925	0.818	0.929	—	—	—	—	—
	269 nm	0.976	0.981	0.986	0.931	0.988	0.961	—	—	—	—
	TPC	0.997*	0.981*	0.998	0.996*	0.998	0.959*	0.984*	—	—	—
	PC	0.996*	0.981*	0.998	0.996*	0.997	0.958*	0.983*	1.000	—	—
	Red	-0.960	-0.929	-0.966	-0.925	-0.966	-0.889	-0.971	-0.977*	-0.976*	—
ABC	FFA	—	—	—	—	—	—	—	—	—	—
	PV	0.674*	—	—	—	—	—	—	—	—	—
	ρ-AV	0.973	0.799*	—	—	—	—	—	—	—	—
	Visco.	0.923	0.801*	0.943	—	—	—	—	—	—	—
	TV	0.965	0.823	0.999	0.945	—	—	—	—	—	—
	233 nm	0.997	0.625*	0.955	0.900	0.945	—	—	—	—	—
	269 nm	0.979	0.743*	0.994	0.910	0.990	0.967	—	—	—	—
	TPC	0.969*	0.781*	0.950*	0.988*	0.941*	0.972*	0.953*	—	—	—
	PC	0.994*	0.860*	0.984*	1.000	0.979*	0.995*	0.986*	0.990*	—	—
	Red	-0.961	-0.759*	-0.987	-0.958	-0.984	-0.946	-0.978	-0.983*	-0.999	—

*There is not significant ($p<0.05$) correlation between each two analysis

As mentioned earlier, there were significant ($p<0.05$) correlations between the analyzed factors in most cases, although some were not significantly correlated ($p>0.05$). That could be due to variability of oil formulations used in this study. For instance, there was a significant ($p<0.05$) correlation between TPC and FFA in formulation A, while no significant relation ($p>0.05$) was observed between them in formulation C. In addition, as indicated in Table 4, the correlation between $E^{1\%}_{1cm}$ at 233 nm and 269 nm was significant ($p<0.05$) in formulation A. In contrast, this correlation was not observed in the other five formulations. This is in accordance with the findings reported in previous studies (Takeoka *et al*., 1997). Furthermore, in most of the formulations, there was a poor correlation between PV and each of the other factors. This was a result of rapid decomposition of hydroperoxides to secondary oxidation products (Tan *et al*., 2002).

In the present study, no significant correlation ($p>0.05$) was observed between TPC and $E^{1\%}_{1cm}$ at 233 nm in all formulations, which is in contrast with Yoon *et al*. (1987). In most cases, TV was significantly ($p<0.05$) correlated with p-AV. This was due to the fact that TV equals 2PV + p-AV, indicating a linear relation between TV with p-AV. TPC in two formulations (A and BC) had a correlation with PC but no significant correlation ($p>0.05$) was obtained in the other four oil treatments, which contradicted the findings reported by Takeoka ***et al.*** (1997). In this study, p-AV had a correlation with both $E^{1\%}_{1cm}$ at 233 and 269 nm. This correlation could be a result of the application of approximately similar procedures to determine primary and secondary oxidation products. In addition, the correlation observed between the aforementioned factors could be attributed to the ascending trend of the analysis conducted within a five-day frying period.

CONCLUSIONS

The results of this study have shown that frying oil A (RBD palm olein) was found to be a suitable frying medium, while the frying oil C (canola oil) was shown to be an unstable frying oil due to its poor physicochemical changes after the frying process. In terms of TPC, treatment ABC (RBD palm olein/sesame oil/canola oil) was found to be the most stable frying medium because it showed the least changes in TPC among all six frying oils. In terms of PV, the frying medium AB (RBD palm olein/sesame oil) showed the highest stability during the frying application compared to the other oils used in this study. Treatment AC showed the least increase in terms of FFA, indicating that AC was resistant against FA formation. Formulation BC was proven to possess the highest stability against formation of PC and this was shown by viscosity changes; BC had the lowest increase in viscosity during a five-day frying period. A and AB showed significantly ($p<0.05$) better frying performance over regular canola oil and its combinations. Overall, blended oil had better physicochemical properties and stability against oxidation during deep fat frying. Based on the Pearson's correlation data obtained, the correlation between variable factors depends on the variability of oil treatments and, in some cases, on frying conditions, which vary from study to study.

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