

Effect of Saturated/Unsaturated Fatty Acid Ratio on Physicochemical Properties of Palm Olein–Olive Oil Blend

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Abstract Although blending polyunsaturated oil with more saturated or monounsaturated oils has been studied extensively, there is no similar information regarding the partial replacement of palm olein with olive oil (OO). Therefore the main objective of this study was to investigate the effects of OO partial replacement (0, 25, 50, 75, 90 and 100% w/w) on the chemical stability of palm olein oil (POO). The physicochemical properties of oil samples namely iodine value, peroxide value (PV), anisidine value, TOTOX value (total oxidation value, TV), free fatty acid (FFA), cloud point, color and viscosity were considered as response variables. Significant differences among the oil blend properties were determined at the significance level of $P < 0.05$. Apart from FFA, all the response variables were significantly influenced by type and concentration of oils. The oil blend containing 10% POO and 90% OO showed the highest TV (6.10); whereas the blend containing 90% POO and 10% OO exhibited the least TV (2.41). This study indicated that the chemical stability of oil blend significantly ($P < 0.05$) increased with increasing the proportion of polyunsaturated/monounsaturated fatty acid.

Keywords Palm olein · Olive oil · Blending · Physicochemical properties · Polyunsaturated fatty acids · Monounsaturated fatty acids

Introduction

Oil may be classified as hard or soft oil depending on saturated or unsaturated fatty acids ratio [1]. If a triglyceride has two or three unsaturated fatty acids, it tends to be liquid at any temperature above 0 °C. The term ‘soft oil’ is used to define the liquid oils containing a very high percentage of unsaturated fatty acids such as corn oil (91%), olive oil (OO) (85%), soybean oil (86%) and grape seed oil (89%) [2]. As mentioned earlier, soft oils which are rich in unsaturated fatty acids can easily oxidize, thus they become chemically unstable. As a rule, the increase in saturated fatty acid content of soft oils reduces the degree of chemical oxidation. Hard oils such as palm oil, palm kernel oil and coconut oil that are generally composed of triglycerides containing two or three saturated fatty acids may be solid or semi-solid state at ambient temperatures.

The evergreen olive cultivar (*Olea europea* L., Oleaceae) is an important Mediterranean tree [3]. Extra virgin olive oil (EVOO) is considered to be the best OO for its organoleptic characteristics, for its oxidative stability and its chemical composition [4]. OO is extracted from the fruit of *Olea europea*. Among vegetable oils, it can be consumed in crude form known as virgin OO. The term “olive-residue oil” applies to the oil obtained from the residue (remaining cake) after mechanical extraction of the oil from olives. The surplus of OO in the Mediterranean region has made it the most commonly used oil for frying applications. OO is a valuable natural product that provides an

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excellent and unique flavor and nutritional benefits. Thus, it is important to preserve these unique characteristics.

The oil palm (*Elaeis guineensis* jacquin) originated from South Africa. In its virgin form, the oil is bright orange–red due to the high content of carotene. Palm oil is the largest potential source of vitamin E, representing mainly tocotrienols (70%) and tocopherols (30%). α -Tocopherol and γ -tocotrienol account for the major portions of the total tocopherols and tocotrienols. The presence of natural vitamin E in palm oil ensures a longer shelf-life for palm-based food products. As the vitamin E acts as an antioxidant, it plays an important role in the stabilization of oils and fats [5, 6]. Palm oil can be fractionated into a low melting liquid fraction known as ‘olein’ and a high melting solid fraction referred to as ‘stearin’. The liquid fraction olein can be used as a frying and cooking oil especially in tropical countries.

The blending of oils has been encouraged in the recent past and it is gaining importance on a nutritional basis, thus blended oils have been used for frying purposes [7, 8]. Oils and fats used for commercial frying applications must be stabilized to prevent any changes caused by oxidation, polymerization or hydrolysis during high temperature use. Modifying the fatty acid composition of the oil is the most common method used to stabilize the frying oil. Blending polyunsaturated oil with more saturated or monosaturated oils is an option to adjust fatty acid levels to optimal level, such as combining high-oleic sunflower oil with corn oil or hydrogenated soybean oil with soybean oil [9, 10] or combining palm-olein with sunflower oil [11]. Previous studies showed that blending of SBO with other oils/fats could improve overall properties [12] as well as oxidative stability. Proper blending of high oleic and high linoleic fatty acid-contained oils may result in the improved oil stability [13]. The main objective of the present study was to investigate the effect of type and concentration of vegetable oils namely palm olein oil (POO) and OO on physicochemical properties of oil blends in order to obtain a physically and chemically stable POO-OO oil blend.

Materials and Methods

Materials

Refined, bleached and deodorized (RBD) POO, pure olive oil (OO) and refrigerated French fries were purchased from a local supermarket (Selangor, Malaysia). Fatty acid methyl ester (FAME) standards were purchased from Sigma–Aldrich (St Louis, MO, USA). Sodium methoxide was purchased from Fisher (Pittsburgh, PA, USA). All other chemicals were either of high-performance liquid chromatography (HPLC) or analytical grade.

Table 1 Ratio of oil blends

Sample number	POO (% w/w)	OO (% w/w)
1	0	100
2	10	90
3	25	75
4	50	50
5	75	25
6	90	10
7	100	0

POO Palm olein oil, OO olive oil

Preparation of Samples

Table 1 shows the oil blends prepared by blending POO (0, 25, 50, 75 and 100% w/w) and OO (0, 25, 50, 75 and 100% w/w). RBD POO (100% w/w) and OO (100% w/w) were considered as control samples.

Determination of Fatty Acid Composition

Fatty acid methyl esters were prepared according to the analytical method provided by the Palm Oil Research Institute of Malaysia [14]. The fatty acid composition was then analyzed using a Hewlett-Packard 6890 GC (Wilmington, DE) equipped with a flame ionization detector (FID) and a polar capillary column BPX70 (0.25 mm \times 30 m \times 0.25 μ m, Victoria, Australia). The oven temperature was programmed in two stages as follows: first, from 50 to 180 $^{\circ}$ C (8 $^{\circ}$ C/min) and then from 180 to 200 $^{\circ}$ C (5 $^{\circ}$ C/min). The carrier gas (helium) flow rate was 6.8 ml/min. Standard methyl esters of fatty acids were used as authentic samples. Identification of unknown peaks was carried out by comparing relative retention times. The peak areas were obtained from the computer and the percentage of the fatty acid were calculated as the ratio of partial area to total area. The fatty acid determination was carried out in duplicate for each sample and the average of two individual measurements was used for further data analysis.

Determination of Melting Behavior and Cloud Point

The melting behavior of samples was investigated using a Perkins-Elmer differential scanning calorimeter (Perkins-Elmer Diamond DSC, Shelton, CT, USA). The instrument was calibrated using indium and zinc. The purge nitrogen gas (99.99%) was used as a carrier gas with a flow rate of 100 ml/min. For thermal analysis, frozen oil (6 ± 0.5 mg) was heated at 60 $^{\circ}$ C in an oven until completely melted and then placed in an aluminum pan. The sample was then cooled to -60 $^{\circ}$ C at a flow rate of 5 $^{\circ}$ C/min and held for

2 min at $-60\text{ }^{\circ}\text{C}$. It was then subjected to the heating procedure ramped from -60 to $60\text{ }^{\circ}\text{C}$ at a rate of $5\text{ }^{\circ}\text{C}/\text{min}$ [15]. The heating thermogram was recorded and the offset (end) temperature was tabulated. The determination of melting point was performed in duplicate for each sample and average of two measurements was employed for data analysis. Cloud point (CP) is used to define the temperature at which the oil begins to cloud, thereby resulting in crystallization under controlled cooling procedure. AOCS official method Cc6–25 [16] was used to determine the CP of samples. CP was checked in duplicate and an average of three individual measurements was used for data analysis.

Determination of Apparent Viscosity and Color

The apparent viscosity of samples was determined using a rheometer (RheoStress 600, Haake, Karlsruhe, Germany). Oscillatory tests (mechanical spectra) were performed using a cone sensor (C35/2° Ti; 222–1,632; 35 mm diameter, 2° angle), with 0.100-mm gap and a measuring plate cover (MPC 35; 222–1,549). Measurement was performed at $25\text{ }^{\circ}\text{C}$ at various shear rates (10–40 1/s), whereby the temperature is commonly considered during product utilization. The data of the rheological measurements was analyzed using the Rheowin Data Manager software Version 3.12. Small-amplitude oscillatory experiments were carried out at log 0.01–50.00% strain to determine the linear viscoelastic region of each sample. All samples were allowed at rest for 1 min after loading to allow temperature equilibration and induced stress to relax. The flow curves giving viscosity η (mPa s) as a function of shear rate (1/s) were characteristic of shear-thinning behavior. The measurements were reported as the average of two individual measurements.

Color was determined by using a Lovibond Tintometer PFX 880 Series (Lange GmbH, Berlin, Germany), according to the PORIM method [14]. Glass cells, 5 1/4 and 1-in. (13.3 and 2.5 cm) path lengths, were used for containing the test samples. All test samples were homogenized to clear liquids by heating them in an oven at $60 \pm 2\text{ }^{\circ}\text{C}$. Results were expressed on the R and Y scale. The color of each sample was determined in duplicate and the average of two individual measurements was employed for data analysis.

Determination of Iodine Value and Free Fatty Acid

The iodine value (IV) of the samples was determined as described in the AOCS Method Cd 1–25 [16]. The sample (0.400 g) was diluted in 15 ml of carbon tetrachloride and 25 ml of Wijs' solution were added. After storing at room temperature in the dark for 1 h, the mixtures were reacted with 20 ml of 1 N potassium iodide and then titrated with 0.1 N sodium thiosulphate solutions [17]. The IV was

measured in duplicate for each sample and the average of two individual measurements was used for data analysis.

Free fatty acid (FFA) was determined according to the PORIM test method [14]. For measurement of FFA, 30 ml of the mixture solvent (ether/ethanol/water, 3:3:2 v/v/v) was used to dissolve 5 g of the sample and then titrated using 0.1 N sodium hydroxide solution [18, 19]. For each sample, FFA was determined in duplicate for each sample and the average of two individual measurements was used for further data analysis. FFA was expressed as % oleic acid. FFA is given by:

$$\text{FFA (\%)} = 25.6 \text{ NV}/\text{W}$$

Determination of Peroxide, Anisidine and TOTOX (Total Oxidation Products) Value

The peroxide value (PV) was evaluated according to AOAC method 28.022,18 using 5 g of oil of each sample. A mixture of oil and chloroform/acetic acid 2:3 (v/v) with a saturated potassium iodide solution was kept in darkness for 1 min for the reaction. The iodine formed was titrated with 0.1 (N) $\text{Na}_2\text{S}_2\text{O}_3$. PV was expressed as milliequivalents of active oxygen per kilogram of oil (mequiv O_2/kg) and calculated using the formula $\text{PV (mequiv } \text{O}_2/\text{kg}) = (\text{volume in ml of } \text{Na}_2\text{S}_2\text{O}_3) \times (0.1 \text{ N}) \times (1,000) \times (\text{g/oil})$. The determination of PV was carried out in duplicate for each sample and the average of two individual measurements was employed for data analysis.

PORIM test methods were used to determine *p*-anisidine values (AV) [14]. The *p*-anisidine method was developed to replace a similar method, the benzidine test, because benzidine is a known carcinogen. The *p*-AV is a measurement of aldehyde content in an oil, principally 2,4-dienals and 2-alkenals. The sample (0.5–4.0 g) was dissolved and diluted to volume with isooctane in a 25 ml volumetric flask. The absorbance of the solution was measured at 350 nm. Exactly 5 ml of the fat solution were transferred to a test tube and 5 ml of only the solvent were added to another test tube. One milliliter of *p*-anisidine reagent (2.5 g/l solution in glacial acetic acid) was added to each tube and shaken. After exactly 10 min, the absorbance of the solution in the first test tube was measured at 350 nm, using the solution in the second test tube as a blank.

$$p - \text{AV} = [25(1.2A_s - A_b)]/m$$

The TOTOX (i.e. total oxidation products) value was introduced for the evaluation of refined oils. The *p*-AV is often used in the industry in conjunction with PV to calculate the TOTOX value given as: $\text{TV} = 2\text{PV} + p\text{-AV}$ [18]. The reason for the multiplication of PV by a factor 2 is that the PV has a more pronounced effect on the stability of refined oil than the AV.

Table 2 Fatty acid composition of POO, OO and their oil blends

Fatty acid	Oil blends (POO:OO)						
	0:100	10:90	25:75	50:50	75:25	90:10	100:00
C12:0	–	0.29	0.29	0.29	0.29	0.29	0.29
C14:0	11.58	10.53	9.51	6.35	3.75	2.16	1.12
C16:0	0.95	4.87	10.77	21.2	30.43	37.14	40.27
C16:1	1.06	1.06	1.07	1.1	1.12	1.41	1.15
C18:0	2.45	2.51	2.6	2.77	2.93	3.035	3.10
C18:1	75.41	72.12	67.22	59.04	58.57	45.96	42.69
C18:2	6.73	7.17	7.84	8.96	10.08	10.75	11.20
C18:3	0.61	0.57	0.53	0.47	0.40	0.37	0.35

POO Palm olein oil, OO olive oil

Statistical Analyses

The data obtained from the measurements were subjected to univariate one way analysis of variance (ANOVA) to determine the significant differences among the samples defined at $P < 0.05$. The physicochemical properties of oil, namely fatty acids composition (FAC), melting behavior, apparent viscosity, color, IV, PV, AV and FFA, were considered as the response variables in this study. All measurements were carried out in duplicate and reported as means \pm SD of independent trials. The data analysis was performed using the Minitab v. 13.2 statistical package (Minitab Inc., State College, PA, USA).

Results and Discussion

Fatty acid Composition

Blending palm oil with OO increased the unsaturated fatty acids, in particular, the oleic acid. Table 2 shows the fatty acid compositions of the samples. Figures 1 and 2 show gas chromatograms obtained from qualitative analysis of

fatty acid composition of POO and OO. The results indicated that the concentration level of C18:1, C16:0 increased with increasing the POO content in the oil blend formulations; while the percentage of C18:3 decreased as the POO content was increased. There was a significant ($P < 0.05$) negative correlation ($r = -0.990$) between IV and C16/C18:2 + C18:3 ratios. The blending of polyunsaturated oil with more saturated or monosaturated oils is to adjust fatty acid levels to an optimal level, such as combining high-oleic sunflower oil with corn oil or hydrogenated soybean oil with soybean oil [9, 10] or combining palm-olein with sunflower oil [11].

Melting Behavior and Cloud Point

The melting points of oils during frying are presented in Table 3. The DSC thermogram shows the changes in melting point of experimental oils (Fig. 3). This technique is used for studying various heat-related phenomena in materials by monitoring associated changes in enthalpy. The end point in DSC thermogram was considered as the melting point. The results demonstrated that the melting point was significantly ($P < 0.05$) influenced by the proportion of POO to OO in oil blend formulation (Table 3). As shown in Table 3, the melting point significantly ($P < 0.05$) increased with an increasing POO content or a decreasing OO concentration level in the oil blend formulation (Table 3). This could be explained by the high proportion of saturated and monounsaturated fatty acids to polyunsaturated fatty acid, thus resulting in a high melting point compared to the oil blend containing a high polyunsaturated fatty acid content. The presence of FFAs, partial glycerides and oxidation products in the oil tend to shift the melting range to a lower temperature, thereby increasing the melting point [15]. On the other hand there was a close correlation ($r = 0.989$) between the melting point and C16/C18:2 + C18:3 ratios. Consequently, the oil blend containing the highest ratio of C16/C18:2 + C18:3

Fig. 1 Gas chromatogram showing the fatty acid composition of palm olein oil

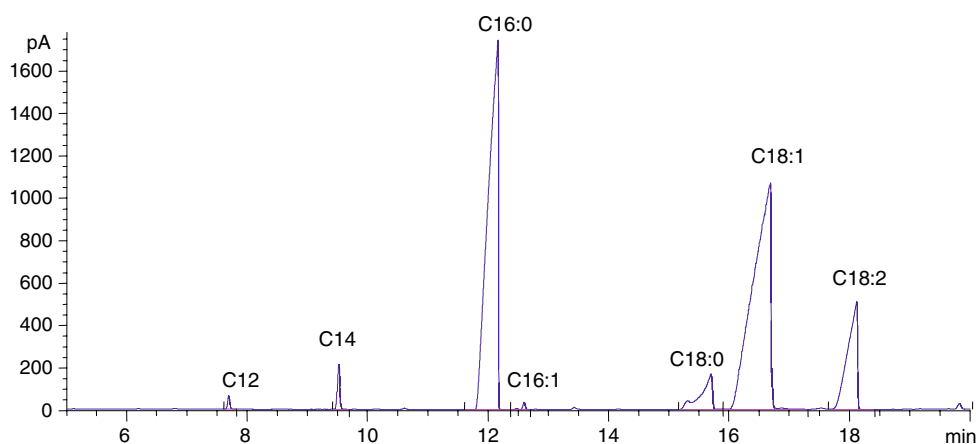
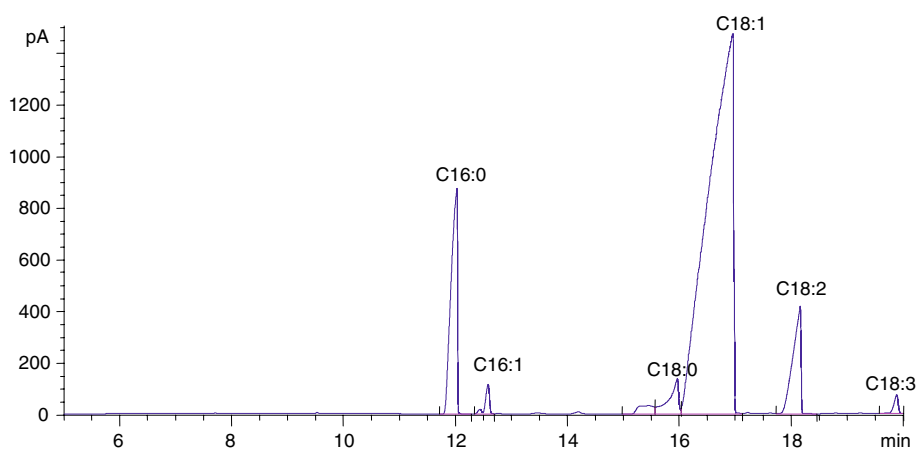
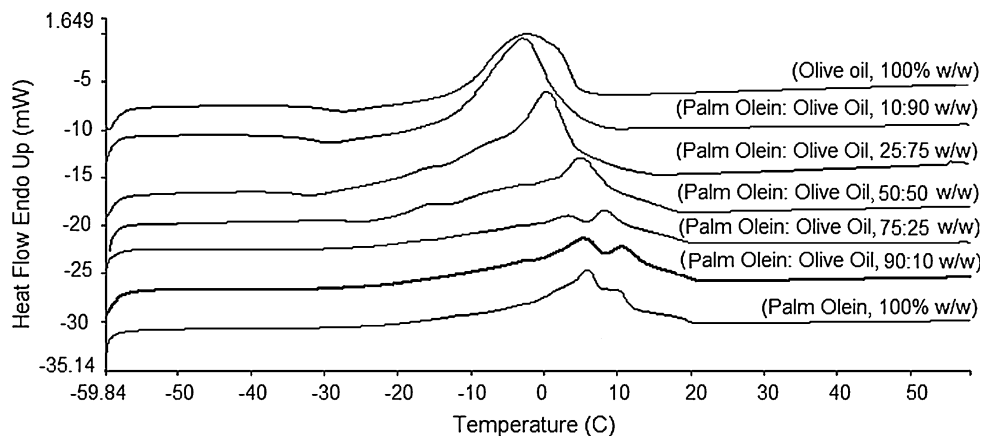


Fig. 2 Gas chromatogram showing the fatty acid composition of olive oil**Table 3** Some physicochemical properties of oil blends as function of POO:OO ratio

POO:OO	0:100	10:90	25:75	50:50	75:25	90:10	100:0
Melting point	7.02 ± 0.07 ^a	8.50 ± 0.008 ^{ab}	10.71 ± 0.15 ^{ab}	14.51 ± 0.02 ^{abc}	18.27 ± 0.48 ^{bc}	20.67 ± 0.44 ^c	22.04 ± 0.67 ^c
Color (yellow)	19.00 ± 0.00 ^a	20.10 ± 0.14 ^b	21.80 ± 0.14 ^c	24.50 ± 0.14 ^d	27.30 ± 0.14 ^e	28.90 ± 0.14 ^f	30 ± 0.00 ^g
Color (red)	2.00 ± 0.00 ^a	2.10 ± 0.14 ^{ab}	2.30 ± 0.14 ^{ab}	2.50 ± 0.14 ^{bc}	2.80 ± 0.14 ^{cd}	2.90 ± 0.14 ^{cd}	3.00 ± 0.00 ^d
TV (2PV + AV)	6.57 ± 0.01 ^a	6.10 ± 0.10 ^b	5.41 ± 0.01 ^c	4.25 ± 0.01 ^d	3.10 ± 0.10 ^e	2.41 ± 0.01 ^f	1.95 ± 0.01 ^g
FFA (%)	0.06 ± 0.00 ^a	0.06 ± 0.00 ^b	0.06 ± 0.00 ^c	0.06 ± 0.00 ^d	0.06 ± 0.00 ^e	0.06 ± 0.00 ^f	0.06 ± 0.00 ^g

POO Palm olein oil, OO olive oil

^{a,b,c,d} Significant ($P < 0.05$) difference between the oil blends and control samples in term of the physicochemical properties

Fig. 3 DSC thermogram indicating the thermal behavior of oil blends

(90% POO) showed the maximum melting point (20.67 °C); whilst the oil blend composed of the lowest ratio of C16/C18:2 + C18:3 (10% OO) showed the lowest melting point (8.50 °C) (Fig. 3).

The CP is a typical physical parameter. It is applied to oleins in order to determine the resistance against crystallization and hence to obtain a quick estimation of their cold stability [20]. As shown in Fig. 4, the type and concentration of RBD vegetable oil had a significant ($P < 0.05$) effect on the CP of oil blends. The results indicated that the CP significantly ($P < 0.05$) increased as the concentration level of POO was increased; whereas

the increase in OO content resulted in a lower CP (Fig. 4). As also illustrated by previous researchers [21], the CP of oil is attributed to the unsaturation degree of fatty acid profile, thus the oil containing a higher concentration level of unsaturated fatty acids shows a lower CP than the oil rich in saturated and/or monounsaturated fatty acids. The significant ($P < 0.05$) positive correlation ($r = 0.987$) observed between CP and C16/C18:2 + C18:3 ratios confirmed this explanation. Hasmadi et al. [22] reported that the CPs of palm olein obtained by fractionating 100% RBD palm oil at 15, 18 and 21 °C ranged from 7.8 to 8.9 °C.

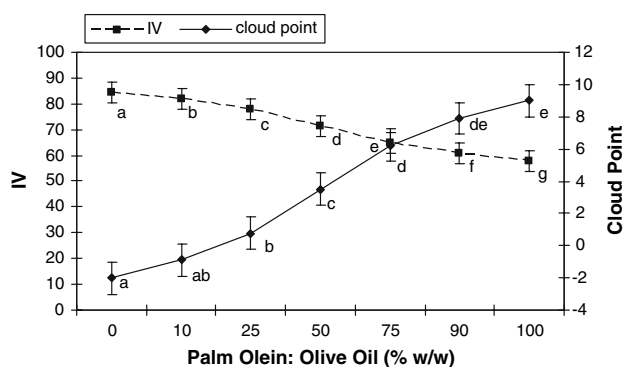


Fig. 4 Effect of POO:OO ratio on the iodine value and cloud point of oil blends

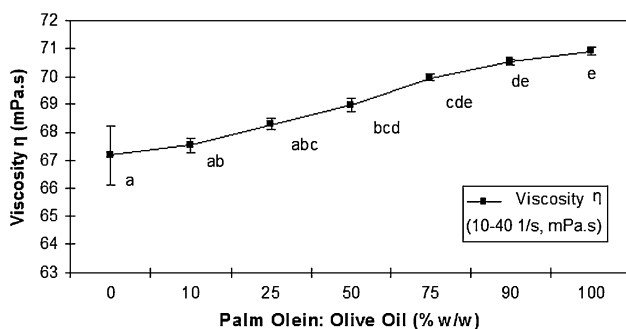


Fig. 5 Effect of POO:OO ratio on the apparent viscosity of POO-OO oil blends

Apparent Viscosity and Color

Viscosity is one of the most commonly used physical parameters to evaluate the extent of frying oil deterioration in commercial and household frying. The change in viscosity is the most obvious change that can be observed even by the non-expert [1]. Figure 5 shows that the ratio of RBD vegetable oils (POO:OO) significantly ($P < 0.05$) affected on the viscosity of prepared oil blends. There was a close direct relationship ($r = 0.965$) between viscosity and C16/C18:2 + C18:3 ratios. As a result, the increase in apparent viscosity was observed by increasing the amount of POO or reducing the OO content. The increase in viscosity could also be related to the presence of high molecular weight polymers. The more viscous the frying oil, the higher degree of polymerization, thus a higher oil deterioration.

The results showed that the magnitude of color was significantly ($P < 0.05$) governed by the proportion of POO to OO (Table 3). The degree of yellow and red color increased with an increase in the amount of POO or a reduction in the OO content. In the present study, the POO (100%) showed the highest degree of the yellow and red color; while the OO (100%) showed the least magnitude of the yellow and red color (Table 3).

Iodine Value and Free Fatty Acids

As clearly indicated in Table 3, the chemical properties of oil blends were significantly ($P < 0.05$) affected by the type and concentration of RBD vegetable oils used for the formulation of the oil blend. The results showed that the IV decreased as the proportion of POO:OO was increased, thus resulting in higher stability against chemical oxidation (Fig. 4). The lowest IV was observed for POO (100%); while the OO (100%) showed the highest magnitude of the IV (Fig. 4). This observation could be due to a decrease in the unsaturated degree of the fatty acid profile induced by the presence of large amounts of saturated and monounsaturated fatty acids. There is another grade of palm olein traded known as ‘superolein’ which has a higher IV than the regular palm olein, and its IV ranges from 60 to 67.5 g iodine/100 g sample. Nor Aini et al. [23] reported that blending POO with sunflower oil produced oleins with a much higher IV than the regular palm olein, superolein or top olein. They also stated that the decrease in IV was in parallel with the decrease in the double bonds of unsaturated fatty acids. The benefit is that these oleins remain clear for a longer duration compared to regular palm olein or superolein. Consumers show a preference for an oil that stays clear.

The free fatty acid level is a measurement of hydrolytic rancidity, caused by a combination of enzymes and moisture. This is a problem mainly encountered in products based on lauric oils, such as coconut and palm kernel oil. The FFAs are liberated from the parent oils, which comprise large amounts of capric, lauric and myristic acids. These acids have a distinct soapy flavor and have lower flavor threshold values than the longer chain fatty acids found in other oils and fats [24]. As shown in Table 3, the POO:OO ratio of the samples had no significant ($P > 0.05$) effect on the FFA content. By changing the amount of palm oil and OO, the FFA level remains unchanged. According to Kun [25], blending RBDPO and vegetable oil is done to reduce the content of linoleic and linolenic acids where the effect is similar to partial hydrogenation without concerns about the formation of *trans* FFA isomers.

Peroxide, Anisidine and TOTOX Values

The peroxide value is a measure of the amount of peroxides formed in fats and oils through autoxidation and oxidation processes. As illustrated by Che Man and Jaswir [26], PV is the degree of initial oxidation of fats and oils. Therefore, a higher PV reflects lower chemical stability. The results indicated that the PV decreased as the content of OO decreased; while the increase in the POO concentration level resulted in a decrease in the PV, thus confirming the oil blend containing higher POO and lower OO contents

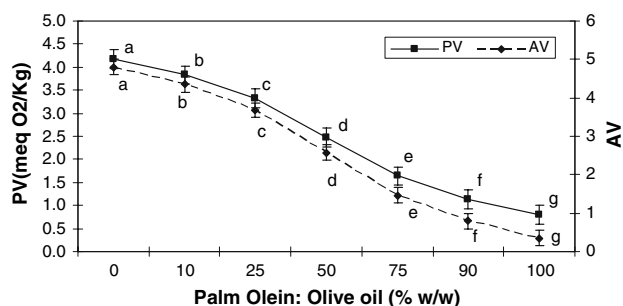


Fig. 6 Effect of POO:OO ratio on peroxide value and anisidine value of oil blends

providing a lower PV or higher chemical stability (Fig. 6). The lowest initial PV was observed for POO (100%); while the OO (100%) showed the highest magnitude of initial PV (Fig. 6). In general, the increase in linoleic acid (C18:2) and/or decrease in oleic acid (C18:1) resulted in a decrease in the chemical oxidative stability of prepared oil blends. The oil blends containing a higher content of linolenic acid (C18:2) and lower percentage of oleic acid (C18:1) showed less stability to the oxidation. However, PV alone is not a suitable parameter to assess the extent of oil deterioration and chemical stability of oil because peroxides and hydroperoxides are unstable compounds. They decompose to carbonyl and aldehydic compounds, thereby reducing the PV [18]. This is the main reason explaining why the amount of peroxides cannot be used as an individual parameter to estimate the chemical stability of oil.

The determination of anisidine values is an empirical test for assessing advanced oxidative rancidity of oils and fats by estimating the secondary oxidation products of unsaturated fatty acids, principally conjugated dienals, 2-alkenals and 2-alkenals. Aldehydes are largely considered responsible for the off-flavors in fats and oils due to their low sensory threshold values [1, 18]. The AV test is particularly useful for abused oils of low PV (frying oils) and for assessing the quality of highly unsaturated oils. The results indicated that the OO content had a significant ($P < 0.05$) positive effect on AV. Conversely, the significant ($P < 0.05$) negative effect of POO content on AV was observed (Fig. 6). The measurement of AV determines the amounts of aldehyde (principally 2-alkenals and 2,4-alkadienals) in animal fats and vegetable oils. This method is used along with PV to assess the oxidative rancidity [27]. Thus, the oil blend containing a higher proportion of POO to OO showed the highest chemical stability (i.e. lower AV) compared to the other formulated oil blends. In fact, the increase in linoleic acid (C18:2) and/or decrease in oleic acid (C18:1) led to a decrease in the AV of oil samples. The oil blend containing a higher content of linolenic acid (C18:2) and a lower percentage of oleic acid (C18:1) showed a higher AV or less stability to the

oxidation. As shown in Fig. 6, the OO (100%) and POO (100%) showed the highest and lowest AVs, respectively.

As shown in Table 3, the magnitude of TV decreased with increasing POO content; whereas the increase in OO concentration level led to increase TV. This observation could be interpreted as a positive correlation between PV and TV. In fact, the increase in the amount of monounsaturated fatty acid (C18:1) resulted in an increase in the oxidative stability of oil blends. Conversely, the presence of a high content of polyunsaturated fatty acids (i.e., C18:2 and C18:3) led to a decrease in the chemical stability of oil blends (Table 3). The results indicated that the oil blend containing 90% (w/w) POO and 10% (w/w) OO showed the highest chemical stability as compared to the other oil blends (Table 3). This finding might be explained by the high proportion of saturated and monounsaturated fatty acids to polyunsaturated fatty acids. The results also indicated a significant ($P < 0.05$) negative correlation ($r = -0.991$) between the Totox value and C16/C18:2 + C18:3 ratios. During heating such as the frying of food products, oils or fats undergo hydrolysis, thermal degradation, oxidation and polymerization. These are enhanced if the fat/oil contains highly unsaturated fatty acids, which result in changes in both physical and chemical properties. In order to minimize these changes, hydrogenation, partial hydrogenation, addition of antioxidants or other oils which have a lower content of highly unsaturated fatty acids have been attempted [28]. Mariod et al. [13] reported suitable blending of high oleic and high linoleic fatty acid-contained oils may result in an improved oil stability. A previous study [12] showed that the blending of SBO with other oils/fats could improve overall properties as well as oxidative stability.

Conclusions

The results indicate that the magnitude of IV, PV, AV, TV, CP and color of oil blends are significantly ($P < 0.05$) influenced by the proportion of POO to OO content in the oil blends before the frying process. The changes in physicochemical properties of oil blends before the frying process could be mainly interpreted by the changes in the fatty acid profile induced by altering the ratio of POO:OO. The oil blend containing 10% (w/w) POO and 90% (w/w) OO provided the highest TV (6.10); while the least TV (2.41) was observed for a combined level of 90% (w/w) POO and 10% (w/w) OO. The IV decreased by increasing the proportion of POO:OO, thereby enhancing the chemical stability against oxidative rancidity. The present study indicated that the oil blends containing a higher amount of POO provided higher chemical stability compared to the other formulated oil blends. This could be explained by the

fact that the presence of a high content of saturated fatty acids (i.e. C16:0) resulted in an increase in the chemical stability of oil blends.

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