

Effect of Microwave Heating on Oxidative Degradation of Sunflower Oil in the Presence of Palm Olein (Kesan Pemanasan Gelombang Mikro Terhadap Pemosotan Oksidatif Campuran Minyak Bunga Matahari dalam Olein Sawit)

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ABSTRACT

The aim of this study was to evaluate on how heat treatments by microwave oven may affect the oxidative degradation of sunflower oil (SFO) and its blend with palm olein (PO). The blend was prepared in the volume ratio of 40:60 (PO: SFO, PSF). The samples were exposed to microwave heating at medium power setting, for different periods. In this study, refractive index, free fatty acid content, peroxide value, p-anisidine value, total oxidation (TOTOX), specific extinction, viscosity, polymer content, polar compounds and food oil sensor value of the oils all increased, whereas iodine value and $C_{18:2}/C_{16:0}$ ratio decreased as microwave heating progressed. Microwave heating temperature increased with increasing heating time and longer heating times resulted in a greater degree of oil deterioration. The percentage of linoleic acid tended to decrease, whereas the percentage of palmitic acid increased. The effect of adding PO to SFO on the formation of free fatty acids and conjugated dienes during microwave treatment was not significant ($p < 0.05$). No significant differences in food oil sensor value was observed between SFO and PSF. Based on the most oxidative stability criteria, it can be concluded that the microwave heating caused the formation of comparatively lower amounts of oxidation products in PSF compared to SFO, indicating a lower extent of oxidative degradation of PSF.

Keywords: Fatty acids; microwave heating; oxidative stability; polar compounds; sunflower oil

ABSTRAK

Tujuan kajian ini dijalankan adalah untuk menilai bagaimana olahan haba oleh ketuhar gelombang mikro boleh mempengaruhi kerosotan oksidatif minyak bunga matahari (SFO) dan campuran dengan olein sawit (PO). Campuran telah disediakan dalam nisbah isi padu 40:60 (PO: SFO, PSF). Sampel didedahkan kepada pemanasan gelombang mikro pada tetapan kuasa sederhana untuk tempoh yang berbeza. Dalam kajian ini, indeks biasan, kandungan asid lemak bebas, nilai peroksida, nilai p-anisidine, pengoksidaan total (TOTOX), kepupusan spesifik, kelikatan, kandungan polimer, sebatian berkutub dan nilai sensor minyak makan bagi semua sampel minyak meningkat, manakala nilai iodin dan nisbah $C_{18:2}/C_{16:0}$ menurun semasa pemanasan gelombang mikro tersebut berlaku. Suhu pemanasan gelombang mikro meningkat dengan pertambahan masa pemanasan dan masa pemanasan yang lebih panjang mengakibatkan tahap kerosotan minyak yang lebih besar. Peratusan asid linoleik cenderung berkurangan, manakala peratusan asid palmitik meningkat. Kesan menambah PO ke dalam SFO terhadap pembentukan asid lemak bebas dan diene berkonjugat hasil olahan gelombang mikro didapati tidak signifikan ($p < 0.05$). Tiada perbezaan yang ketara dalam nilai sensor minyak makan yang diperhatikan antara SFO dan PSF. Berdasarkan kriteria kestabilan oksidatif paling utama, dapat disimpulkan bahawa pemanasan gelombang mikro telah menyebabkan pembentukan jumlah produk pengoksidaan yang agak rendah dalam PSF berbanding SFO dan ini menunjukkan tahap kerosotan oksidatif PSF yang lebih rendah.

Kata kunci: Asid lemak; kestabilan oksidatif; minyak bunga matahari; pemanasan mikro gelombang; sebatian berkutub

INTRODUCTION

Today, microwave heating offers the food industry an opportunity to develop new food products with high nutritional and sensory quality, novel texture, food safety and an extended shelf-life. Heating of food in a microwave oven is caused by interaction of an electromagnetic field with the chemical constituents of food. These interaction comprising of molecular friction and excitation generate heat necessary for cooking purposes (Yoshida et al. 2001). Fats have a great capacity for storing microwave energy,

although they have a small dielectric loss (Mohsenin 1984). This is due to the fact that compared with other foods, they also have a lower specific conductivity and specific heat at constant pressure (Jowitt 1983). It was found that the rate of quality deterioration, such as oxidation, depends on the polyunsaturated fatty acid (PUFA) content (Yoshida et al. 1990). In vegetable oils exposed to microwave energy, the higher the amount of polyunsaturated fatty acids in the oils, the greater was the rate of quality deterioration of the oils. The levels of free fatty acids also increased in vegetable

oil heated in microwave oven (Yoshida et al. 1992). PO is available in huge amounts to a comparatively low price. It has been shown as highly monounsaturated oil, which is rich in oleic acids (Nor Aini et al. 1993), is currently touted to be oxidatively stable. SFO is a rich source of vitamin E and contains alpha-tocopherol. It has a high level of linoleic acid (Huang et al. 1981). High reactivity of this unsaturated fatty acid (USFA) is associated with oxidation, loss of nutritional value and quality (Labuza 1971). Addition of oxidative-stable PO to heat sensitive SFO, might affect the oxidative stability of SFO during microwave heating. Oxidative stability is one of the most important indicators for maintaining the quality of edible oils.

The number of studies concerning the influence of microwave heating on the quality and stability of some vegetable oils including PO and SFO (Emma et al. 2010; Hassanein et al. 2003; Lukešová et al. 2009) have been conducted. Very few studies have analyzed the changes in oil blends (Bendini et al. 2009; Minar et al. 2003) and nothing has been reported on the oxidative degradation of SFO blended with PO during microwave heating. Consequently, the objective of this research was to investigate the change in oxidative degradation of SFO and its blend with 40% PO during microwave heating at medium power setting.

MATERIALS AND METHODS

MATERIALS

Refined sunflower oil (Wintercorn Edible Products, Australia) and palm olein (Sime Darby Food and Beverages, Malaysia) were purchased from local super market. The vegetable oil blend was formulated by blending PO with SFO in the volume ratio of 40:60 (PO:SFO, PSF). All chemicals and solvents used were of analytical grade. *p*-Anisidine and silica gel were products of Merck (Darmstadt, Germany). Standards of fatty acid methyl esters were purchased from Supelco Chemical Co. (Bellefonte, PA, USA). All other chemicals and solvents were from J.T. Baker (Phillipsburg, USA) or RCI Labscan Ltd. (Pathumwan, Thailand) unless otherwise stated.

MICROWAVE HEATING OPERATION

A domestic microwave oven (Model NN-ST65IM, Panasonic Co. Ltd., China) was used in this study. Ninety mL of oil were divided into two 50 mL beakers, which were placed at equal distances on the turntable rotary plate of the microwave oven. The samples were exposed to microwave heating at medium power setting, for different periods (2, 4, 8, 12, 16 and 20 min). The two samples were combined after microwave treatment and before analysis. The final oil temperatures at various heating times were measured by inserting a calibrated thermocouple (Model HI 9043, Hanna Instruments Ltd., Bedfordshire, UK) into the oil immediately after removal from the oven. Finally, the samples were collected and stored at -16°C for analysis.

OIL ANALYSIS

Fatty acid composition of the oils was determined as their methyl esters prepared by the PORIM (PORIM 1995) test method p3.4. Fatty acid methyl esters (FAME) were quantified using an auto-system XL gas chromatograph (Perkin Elmer Incorporate, Massachusetts, USA) equipped with a fused silica capillary column (60 m × 0.25 mm i.d × 0.20 μm film thickness, Perkin Elmer, USA) and a flame ionization detector. The initial temperature of oven was set to 100°C, raised to 170°C at 20°C/min, then programmed to 230°C at 10°C/min and finally heated to 250°C at 30°C/min. The detector and injector temperatures were both maintained at 250°C. Refractive index (method Cc 7-25), free fatty acid content (method Ca 5a-40), iodine value (method Cd 1b-87) and peroxide value (method Cd 8-53) were determined according to American Oil Chemists' Society official methods (AOCS 1987). Determination of specific extinctions (method p2.15) and *p*-Anisidine value (method p2.4) were carried out according to the PORIM (PORIM 1995) test methods. Viscosity of the oils was measured by using a Brookfield DV-II+ viscometer (Brookfield Engineering Laboratories Inc., Middleboro, USA). Polymer compounds were analyzed based on the method described by Peled et al. (1975). Total polar compounds were determined by means of mini column method (Dobarganes et al. 2000). Food oil sensor (FOS) values were measured by using the food oil sensor instrument (CapSens 5000, C-Cit Ag, Wädenswil, Switzerland).

STATISTICAL ANALYSIS

All data were expressed as the mean and standard deviation (SD) and were subjected to one way analysis of variance (ANOVA). Mean values were compared at $p < 0.05$ significant level by Duncan's multiple range test using SPSS 11.5 software package.

RESULTS AND DISCUSSION

The fatty acids composition of the samples examined in this study are summarized in Table 1. The fresh PO was characterized with high levels of palmitic (37.30%) and oleic acid (45.22%) while the fresh SFO stood out for its high level of linoleic acid (51.20%) followed by oleic acid (38.23%) and then palmitic acid (6.28%). The oil containing PO had more palmitic acid and less linoleic and linolenic acids than the oil containing no PO. *Trans* C_{18:2} was found in fresh SFO (0.26%) and in the sample (0.23%) obtained only after 8 min of heating. *Trans* C_{18:2} was also detected in the blend PSF (0.16 to 0.19%) as a result of adding PO that contained 0.09 to 12.00% *trans* C_{18:2}. No *trans* C_{18:1} was detected in any sample used in this study. In most of the samples, palmitic acid increased while linoleic acid decreased with increasing heating times. The increase of palmitic acid could be due to the reduction of double bond in linoleic acid. Upon heating, the ratio C_{18:2}/C_{16:0} decreased in the samples. Similar patterns were observed

TABLE 1. Fatty acid composition (%) of palm olein, sunflower oil and their blend during microwave heating

Sample	Time (min)	C _{12:0}	C _{14:0}	C _{16:0}	C _{16:1}	C _{18:0}	C _{18:1}	C _{18:2}	TransC _{18:2}	C _{18:3}	C _{20:0}	C _{20:1}	C _{24:0}	SFA	MUFA	PUFA	C _{18:2} /C _{16:0}
PO	0	0.22	1.00	37.30	0.14	3.53	45.22	11.90	0.11	0.31	0.27	ND	ND	42.32	45.36	12.21	0.32
	2	0.22	1.00	37.41	0.20	3.58	45.10	11.83	0.12	0.31	0.27	0.03	ND	42.48	45.33	12.14	0.32
	4	0.22	1.00	37.54	0.20	3.54	45.04	11.84	0.10	0.31	0.23	ND	ND	42.53	45.24	12.15	0.32
	8	0.21	1.00	37.39	0.13	3.54	45.40	11.69	0.12	0.31	0.23	ND	ND	42.37	45.53	12.00	0.32
	12	0.22	1.00	37.66	0.20	3.56	44.96	11.80	0.10	0.30	0.23	ND	ND	42.67	45.16	12.10	0.32
	16	0.21	1.00	37.84	0.15	3.56	44.45	11.63	0.09	0.30	0.23	ND	ND	42.84	44.60	11.93	0.31
SFO	0	0.04	0.08	6.28	0.07	2.87	38.23	51.20	0.26	0.57	0.15	0.04	0.26	9.68	38.34	51.77	8.19
	2	0.03	0.07	6.28	0.07	2.89	38.65	51.05	ND	0.56	0.14	ND	0.26	9.67	38.72	51.61	8.13
	4	0.04	0.08	6.29	0.07	2.94	38.36	51.12	ND	0.58	0.19	0.04	0.28	9.82	38.47	51.70	8.13
	8	0.04	0.07	6.25	0.07	2.94	38.41	51.26	ND	0.57	0.13	0.04	0.25	9.68	38.52	51.83	8.20
	12	0.04	0.08	6.28	0.08	2.92	38.41	50.94	0.23	0.62	0.25	0.04	0.28	9.85	38.53	51.56	8.15
	16	0.05	0.09	6.34	0.09	2.92	38.45	50.96	ND	0.59	0.20	0.04	0.30	9.90	38.58	51.55	8.04
PSF	0	0.11	0.45	19.00	0.10	3.19	41.28	34.82	0.17	0.50	0.18	0.04	0.17	23.10	41.42	35.32	1.84
	2	0.11	0.45	19.16	0.10	3.20	41.17	34.78	0.19	0.51	0.18	0.04	0.16	23.26	41.31	35.29	1.83
	4	0.11	0.45	19.42	0.10	3.18	41.55	34.15	0.19	0.50	0.18	0.04	0.16	23.50	41.69	34.65	1.77
	8	0.11	0.45	19.69	0.10	3.28	40.92	34.49	0.16	0.47	0.21	0.03	0.18	23.92	41.05	34.96	1.76
	12	0.12	0.46	19.61	0.10	3.21	41.50	33.98	0.18	0.50	0.18	0.04	0.15	23.73	41.64	34.48	1.74
	16	0.11	0.46	19.77	0.10	3.24	41.64	33.64	0.19	0.49	0.19	0.04	0.16	23.93	41.78	34.13	1.71
20	0.1	0.40	17.23	0.12	2.88	47.89	27.64	0.19	2.96	0.29	0.22	0.14	21.04	48.23	30.60	1.61	

ND- not detected.

by Tan et al. (2002). The results showed that oxidation process progressed rapidly in the SFO as compared to its blend. The blending PO with SFO led to decline the reduction in the ratio of $C_{18:2}/C_{16:0}$. The highest decreased amount from the initial was observed for the SFO (0.29 unit) followed by PSF (0.23 unit) with the least in PO (0.01 unit). The present results showed adding PO slowed down the rate of oxidative degradation of SFO.

RI values of oil samples were increased significantly ($p < 0.05$) as the heating time performed by the oils increased (Table 2). In this case, the amount of RI increment in SFO (0.0020 unit from initial) was similar to that of its blend PSF (0.0021 unit from initial). These results could not be explained by the differences in fatty acids composition where SFO contained higher amount of PUFA compared to its blend. But RI values of the blend at corresponding heating times were significantly lower ($p < 0.05$) compared to SFO. The accumulation of free fatty acid (FFA) contents of the oils were insignificantly increased ($p < 0.05$) with increasing heating time (Table 2). At the end of heating, the amount of FFA was found to be slightly higher in the blend PSF (0.19) compared to SFO (0.17). No significant difference ($p < 0.05$) in FFA levels through the heating periods was observed between SFO and its blend. Addition of PO to SFO at the level of 40% caused slightly higher increment of the FFA values in SFO at heating process; this might be due to the higher rate of increment of FFA in PO during heating. De Marco et al. (2007) reported that the increment in FFA was significantly higher in palm oil than

in the sunflower/palm oil blend (65:35 v/v) during frying. The iodine value (IV) for microwave heated PO, SFO and PSF gradually decreased with increasing heating times (Table 2). The reduction in IV was highest in SFO (5.73) and lowest in PSF (4.11). However, exposing the oils to microwave heating decrease the IV of the oils at significant level ($p < 0.05$). Blending PO with SFO results in slower rate of decrease in the double bond; therefore, the rate of oxidation of blend was lower compared to pure SFO.

Table 3 shows the peroxide value (PV) of the SFO as affected by the PO over microwave heating periods. Oil samples exhibited maximum PV values at 12 min of heating as follows: 9.07 in SFO and 7.18 in PSF. The rancidity is related to PV increase, but hydro-peroxides are unstable under heating at high temperatures. In the present study, addition of PO significantly decreased ($p < 0.05$) the increment of peroxide value of SFO which might be attributed to decreasing amount of linoleic acids present in the blend. Compared to PV, the *p*-anisidine value (*p*-AV) is a more reliable and meaningful test, because it measures the secondary oxidation products, which are more stable during the heating process (Al-Kahtani 1991). The *p*-AVs in all the oils increased significantly ($p < 0.05$) with heating time during microwave heating operation (Table 3). SFO exhibited the highest *p*-AV at each treatment time, as consequence of a higher rate of secondary lipid oxidation product formation probably due to a higher content of linoleic and linolenic acids with respect to its blend, PSF. The SFO containing 40% of PO underwent the *p*-AV increases

TABLE 2. Refractive index, FFA and I_2 values of palm olein, sunflower oil and their blend during microwave heating

Parameters	Time (min)	Palm olein (PO)	Sunflower oil (SFO)	Palm olein : Sunflower oil (PSF)
Refractive index (25°C)	0	1.4639 ± 0.00 ^{Aa}	1.4723 ± 0.00 ^{Ac}	1.4691 ± 0.00 ^{Ab}
	2	1.4648 ± 0.00 ^{Ba}	1.4728 ± 0.00 ^{Bc}	1.4695 ± 0.00 ^{Bb}
	4	1.4651 ± 0.00 ^{Bca}	1.4730 ± 0.00 ^{Bc}	1.4701 ± 0.00 ^{Cb}
	8	1.4654 ± 0.00 ^{BCDa}	1.4734 ± 0.00 ^{Cc}	1.4703 ± 0.00 ^{Db}
	12	1.4658 ± 0.00 ^{CDEa}	1.4737 ± 0.00 ^{Dc}	1.4706 ± 0.00 ^{Eb}
	16	1.4660 ± 0.00 ^{DEa}	1.4738 ± 0.00 ^{Dc}	1.4708 ± 0.00 ^{Fb}
	20	1.4662 ± 0.00 ^{Ea}	1.4743 ± 0.00 ^{Ec}	1.4712 ± 0.00 ^{Gb}
Free fatty acid (%)	0	0.11 ± 0.02 ^{Aa}	0.10 ± 0.00 ^{Aa}	0.11 ± 0.02 ^{Aa}
	2	0.15 ± 0.05 ^{ABa}	0.13 ± 0.01 ^{Ba}	0.14 ± 0.02 ^{ABa}
	4	0.19 ± 0.01 ^{BCc}	0.14 ± 0.01 ^{Ba}	0.15 ± 0.03 ^{ABab}
	8	0.20 ± 0.01 ^{BCc}	0.14 ± 0.01 ^{Ba}	0.16 ± 0.02 ^{ABa}
	12	0.20 ± 0.01 ^{Cc}	0.15 ± 0.01 ^{Ba}	0.16 ± 0.03 ^{ABa}
	16	0.21 ± 0.01 ^{Cc}	0.15 ± 0.01 ^{Ba}	0.18 ± 0.03 ^{Bab}
	20	0.23 ± 0.01 ^{Ca}	0.17 ± 0.02 ^{Ca}	0.19 ± 0.03 ^{Ba}
Iodine value	0	57.67 ± 0.24 ^{Da}	129.84 ± 0.37 ^{Dc}	102.61 ± 0.28 ^{Eb}
	2	56.80 ± 0.38 ^{CDa}	129.33 ± 0.30 ^{CDc}	101.50 ± 0.34 ^{Db}
	4	56.45 ± 0.27 ^{BCa}	128.16 ± 0.54 ^{Cc}	100.43 ± 0.03 ^{Cb}
	8	55.69 ± 0.40 ^{Ba}	126.59 ± 0.91 ^{Bc}	100.36 ± 0.45 ^{Cb}
	12	55.73 ± 0.53 ^{Ba}	125.94 ± 0.95 ^{Bc}	99.28 ± 0.20 ^{Bb}
	16	54.79 ± 0.45 ^{Aa}	124.34 ± 0.17 ^{Ac}	98.51 ± 0.41 ^{Ab}
	20	54.29 ± 0.49 ^{Aa}	124.11 ± 0.55 ^{Ac}	98.50 ± 0.26 ^{Ab}

Each value in the table represents the mean of three replicates ± SD

Values within a row with the same lowercase letters are not significantly different at $P < 0.05$

Values within a column with the same uppercase letters are not significantly different at $P < 0.05$

TABLE 3. Peroxide, *p*-Anisidine and TOTOX values of palm olein, sunflower oil and their blend during microwave heating

Parameters	Time (min)	Palm olein (PO)	Sunflower oil (SFO)	Palm olein : Sunflower oil (PSF)
Peroxide value (meqO ₂ /kg of oil)	0	1.18 ± 0.02 ^{Aa}	1.19 ± 0.10 ^{Aa}	1.18 ± 0.07 ^{Aa}
	2	3.17 ± 0.15 ^{Ba}	4.73 ± 0.27 ^{Bc}	3.73 ± 0.23 ^{Bb}
	4	4.39 ± 0.46 ^{Da}	4.94 ± 0.25 ^{Bb}	5.05 ± 0.05 ^{Cb}
	8	5.77 ± 0.12 ^{Ea}	6.67 ± 0.74 ^{Cb}	6.05 ± 0.15 ^{Da}
	12	6.44 ± 0.10 ^{Fa}	9.07 ± 0.36 ^{Ec}	7.18 ± 0.07 ^{Fb}
	16	4.16 ± 0.11 ^{CDa}	7.82 ± 0.15 ^{Dc}	6.62 ± 0.19 ^{Eb}
	20	3.77 ± 0.43 ^{Ca}	7.40 ± 0.85 ^{CDc}	5.05 ± 0.10 ^{Cb}
<i>p</i> -Anisidine value	0	2.39 ± 0.04 ^{Aa}	2.59 ± 0.12 ^{Aa}	2.55 ± 0.32 ^{Aa}
	2	2.79 ± 0.04 ^{Ba}	6.17 ± 0.25 ^{Bc}	5.28 ± 0.03 ^{Bb}
	4	4.24 ± 0.09 ^{Ca}	8.23 ± 0.25 ^{Cc}	7.16 ± 0.08 ^{Cb}
	8	6.20 ± 0.12 ^{Da}	13.20 ± 0.11 ^{Dc}	12.55 ± 0.09 ^{Db}
	12	7.65 ± 0.10 ^{Ea}	16.34 ± 0.19 ^{Ec}	15.65 ± 0.21 ^{Eb}
	16	10.61 ± 0.13 ^{Fa}	19.13 ± 0.09 ^{Fc}	18.43 ± 0.10 ^{Fb}
	20	13.18 ± 0.10 ^{Ga}	20.89 ± 0.19 ^{Gc}	19.98 ± 0.35 ^{Gb}
TOTOX value (2PV + <i>p</i> -AV)	0	4.74 ± 0.02 ^{Aa}	4.97 ± 0.08 ^{Aa}	4.91 ± 0.12 ^{Aa}
	2	9.13 ± 0.31 ^{Ba}	15.62 ± 0.30 ^{Bc}	12.73 ± 0.48 ^{Bb}
	4	15.02 ± 0.84 ^{Ca}	18.12 ± 0.61 ^{Cb}	17.26 ± 0.14 ^{Cb}
	8	18.09 ± 1.00 ^{Da}	26.53 ± 1.48 ^{Db}	24.59 ± 0.34 ^{Db}
	12	20.52 ± 0.24 ^{Fa}	31.99 ± 0.34 ^{Ec}	28.89 ± 0.16 ^{Eb}
	16	18.94 ± 0.29 ^{Ea}	37.27 ± 0.63 ^{Gc}	32.78 ± 0.10 ^{Gb}
	20	20.72 ± 0.79 ^{Fa}	35.70 ± 1.83 ^{Fc}	30.09 ± 0.16 ^{Fb}

Each value in the table represents the mean of three replicates ± SD

Values within a row with the same lowercase letters are not significantly different at $p < 0.05$

Values within a column with the same uppercase letters are not significantly different at $p < 0.05$

(17.43 units from the initial); being lower than that of SFO (18.30 units from the initial). However, PO addition decelerated the formation of secondary oxidation products in SFO. *p*-AV is often used in the industry in conjunction with PV to calculate the so-called total oxidation or TOTOX value given as: TOTOX = 2PV + *p*-AV (Shahidi & Wanasundara 2002). During the heating process TOTOX values increased significantly ($p < 0.05$) with heating times (Table 3). The lower TOTOX value of the blend indicated more stable to oxidative rancidity than SFO.

The ultraviolet absorption at 233 and 269 nm ($E^{1\%}_{233}$ and $E^{1\%}_{269}$) for most of the samples increased insignificantly ($p < 0.05$) with the increment of heating times (Table 4). No significant ($p < 0.05$) differences were recorded at corresponding heating times in the oil absorptivity at 233 nm between SFO and PSF. Significant ($p < 0.05$) differences were found in $E^{1\%}$ values at 269 nm only after 8 min of heating and these values of SFO increased higher than those of PSF. It was found that in all the samples, the levels of conjugated dienes were higher than trienes; this is indicated by the higher values of $E^{1\%}$ at 233 nm. However, PO addition decelerated conjugated dienes and trienes formation in SFO; but not significantly ($p < 0.05$) enough for all microwave heating times. The viscosity of microwave heated oils increased significantly ($p < 0.05$) with heating times (Table 4). PO had highest initial viscosity as compared to SFO or its blend. During heating, PO showed significantly ($p < 0.05$) higher values at corresponding heating times. The viscosities in SFO were found to be significantly lower

($p < 0.05$) than those of its blend throughout the heating operation; this might be due to the higher initial value of PO. But the amount of increment in SFO from the initial was 7.10 units; being higher than 6.47 units detected in PSF.

As can be seen from Table 5, polymer content (PC) increased significantly ($p < 0.05$) with different rates over 20 min of the heating operation. The increase in PC was due to the formation of higher molecular weight substances by polymerization occurring at elevated temperature (Peled et al. 1975). The increase amounts in PC from the initial were 0.61, 1.55 and 1.24 unit for the media PO, SFO and PSF, respectively. The present results showed the PO sample with the lowest PC while SFO accumulated polymer as highest. No significant differences in PC were observed up to 4 min between the SFO and PSF. The oil containing a higher percentage of PUFA shows the greater tendency to form polymeric compounds rather than a highly SFA containing oil. The amounts of total polar compound (TPC) in the samples increased with the time increment and the rates of increments were significantly different ($p < 0.05$) from each other (Table 5). The faster increment in TPC levels observed for the sample SFO could be attributed to its higher degree of unsaturation. Addition of PO to the pure SFO resulted in a marked decline in TPC value of SFO, thus showing enhancement of the oxidative state of SFO. The FOS values increased significantly ($p < 0.05$) at different rates with the heating times (Table 5). As the number of polar molecules increases, the FOS value of the oil increases. In this case, the highest TPC content and FOS values were both detected

TABLE 4. Specific extinctions and viscosity of palm olein, sunflower oil and their blend during microwave heating

Parameters	Time (min)	Palm olein (PO)	Sunflower oil (SFO)	Palm olein : Sunflower oil (PSF)
$E_{1\text{cm}}^{1\%}$ at 233 nm	0	0.97 ± 0.03 ^{Aa}	1.14 ± 0.03 ^{Ab}	1.10 ± 0.05 ^{Aab}
	2	0.99 ± 0.10 ^{Ba}	1.35 ± 0.03 ^{Bb}	1.30 ± 0.11 ^{Bb}
	4	1.10 ± 0.10 ^{BCa}	1.67 ± 0.04 ^{Cb}	1.44 ± 0.14 ^{Bb}
	8	1.17 ± 0.10 ^{BCa}	1.82 ± 0.09 ^{CDc}	1.54 ± 0.14 ^{Bb}
	12	1.22 ± 0.05 ^{CDa}	1.92 ± 0.09 ^{DEb}	1.80 ± 0.07 ^{Cb}
	16	1.25 ± 0.05 ^{DEa}	2.05 ± 0.09 ^{EFb}	1.92 ± 0.10 ^{CDb}
	20	1.31 ± 0.06 ^{Ea}	2.21 ± 0.12 ^{Fb}	2.11 ± 0.17 ^{Db}
$E_{1\text{cm}}^{1\%}$ at 269 nm	0	0.47 ± 0.03 ^{Aa}	0.55 ± 0.05 ^{Aa}	0.47 ± 0.06 ^{Aa}
	2	0.49 ± 0.01 ^{ABa}	0.75 ± 0.03 ^{Bb}	0.74 ± 0.03 ^{Bb}
	4	0.52 ± 0.01 ^{BCa}	0.98 ± 0.02 ^{Cb}	0.95 ± 0.02 ^{Cb}
	8	0.55 ± 0.01 ^{Ca}	1.07 ± 0.04 ^{Db}	1.02 ± 0.02 ^{Db}
	12	0.60 ± 0.02 ^{CDa}	1.12 ± 0.03 ^{Dc}	1.05 ± 0.02 ^{Db}
	16	0.67 ± 0.06 ^{Da}	1.25 ± 0.03 ^{Ec}	1.15 ± 0.02 ^{Eb}
	20	0.70 ± 0.05 ^{Da}	1.26 ± 0.02 ^{Ec}	1.17 ± 0.02 ^{Eb}
Viscosity (cP)	0	39.63 ± 0.12 ^{Ac}	30.13 ± 0.09 ^{Aa}	35.63 ± 0.12 ^{Ab}
	2	40.03 ± 0.05 ^{Bc}	32.20 ± 0.08 ^{Ba}	36.17 ± 0.12 ^{Bb}
	4	41.00 ± 0.16 ^{Cc}	32.63 ± 0.12 ^{Ca}	37.33 ± 0.12 ^{Cb}
	8	42.07 ± 0.12 ^{Dc}	33.07 ± 0.17 ^{Da}	38.60 ± 0.08 ^{Db}
	12	42.77 ± 0.12 ^{Ec}	33.73 ± 0.12 ^{Ea}	40.30 ± 0.16 ^{Eb}
	16	43.87 ± 0.12 ^{Fc}	34.27 ± 0.12 ^{Fa}	41.07 ± 0.17 ^{Fb}
	20	45.50 ± 0.08 ^{Gc}	37.23 ± 0.05 ^{Ga}	42.10 ± 0.14 ^{Gb}

Each value in the table represents the mean of three replicates ± SD.

Values within a row with the same lowercase letters are not significantly different at $p < 0.05$.

Values within a column with the same uppercase letters are not significantly different at $p < 0.05$.

TABLE 5. Polymer content, total polar compound and FOS value of palm olein, sunflower oil and their blend during microwave heating

Parameters	Time (min)	Palm olein (PO)	Sunflower oil (SFO)	Palm olein : Sunflower oil (PSF)
Polymer content (%)	0	0.54 ± 0.02 ^{Aa}	0.71 ± 0.05 ^{Ab}	0.62 ± 0.03 ^{Aab}
	2	0.65 ± 0.03 ^{ABa}	0.83 ± 0.04 ^{Ab}	0.90 ± 0.07 ^{Bb}
	4	0.74 ± 0.06 ^{BCa}	1.07 ± 0.09 ^{Bb}	0.99 ± 0.02 ^{Bb}
	8	0.80 ± 0.04 ^{BCa}	1.41 ± 0.05 ^{Cc}	1.12 ± 0.08 ^{Cb}
	12	0.90 ± 0.07 ^{CDa}	1.60 ± 0.05 ^{Dc}	1.33 ± 0.04 ^{Db}
	16	1.04 ± 0.14 ^{DEa}	1.89 ± 0.06 ^{Ec}	1.58 ± 0.04 ^{Eb}
	20	1.15 ± 0.07 ^{Ea}	2.26 ± 0.06 ^{Fc}	1.86 ± 0.06 ^{Fb}
Total polar compound (%)	0	6.31 ± 0.16 ^{Ac}	3.14 ± 0.12 ^{Aa}	5.23 ± 0.18 ^{Ab}
	2	6.53 ± 0.09 ^{Aa}	7.19 ± 0.15 ^{Bb}	7.00 ± 0.02 ^{Bb}
	4	7.45 ± 0.18 ^{Ba}	10.11 ± 0.10 ^{Cc}	9.21 ± 0.09 ^{Cb}
	8	7.89 ± 0.29 ^{Ca}	13.24 ± 0.23 ^{Dc}	11.26 ± 0.19 ^{Db}
	12	9.01 ± 0.23 ^{Da}	15.21 ± 0.15 ^{Ec}	13.13 ± 0.09 ^{Eb}
	16	10.40 ± 0.13 ^{Ea}	17.46 ± 0.24 ^{Fc}	15.43 ± 0.17 ^{Fb}
	20	12.03 ± 0.15 ^{Fa}	19.74 ± 0.23 ^{Gc}	17.52 ± 0.29 ^{Gb}
FOS value	0	1.00 ± 0.02 ^{Aa}	1.13 ± 0.05 ^{Aa}	1.07 ± 0.02 ^{Aa}
	2	1.12 ± 0.06 ^{Ba}	1.22 ± 0.03 ^{Ab}	1.19 ± 0.01 ^{ABb}
	4	1.15 ± 0.05 ^{BCa}	1.30 ± 0.04 ^{Bb}	1.25 ± 0.04 ^{Bb}
	8	1.17 ± 0.04 ^{CDa}	1.35 ± 0.04 ^{Cb}	1.32 ± 0.03 ^{Cb}
	12	1.20 ± 0.01 ^{Da}	1.47 ± 0.05 ^{Db}	1.40 ± 0.03 ^{Db}
	16	1.22 ± 0.05 ^{Eab}	1.52 ± 0.06 ^{Eb}	1.44 ± 0.04 ^{Eab}
	20	1.25 ± 0.05 ^{Fa}	1.67 ± 0.05 ^{Fb}	1.57 ± 0.03 ^{Fb}

Each value in the table represents the mean of three replicates ± SD.

Values within a row with the same lowercase letters are not significantly different at $p < 0.05$.

Values within a column with the same uppercase letters are not significantly different at $p < 0.05$.

in SFO and the lowest in PO. Though the FOS value of SFO reduced as the result of PO adding during the microwave heating, the effect of PO addition at the level of 40% on the FOS value were statistically insignificant ($p < 0.05$).

CONCLUSION

In this study, most of the degradative indicators suggested that the degradation rate was the fastest in SFO compared to PO or PSF. Based on the results, it can be concluded that addition of PO to SFO at 40% (v/v) slowed down the oxidative degradation rate of the SFO; this might be due to larger quantities of PUFA present in fresh SFO compared to PO. But no significant differences in the levels of some indices such as FFA, $E^{1\%}$ at 233 and FOS were found between the samples SFO and PSF. Although many changes occurred in the oil quality indicators during heating, the maximal values for FFA and PV remained within the acceptable limits for edible oils, showing that microwave heating does not lead to major degradation of the oil quality. Other conventional heating techniques and trials in real cooking condition could be carried out to complete the present work.

ACKNOWLEDGMENTS

The authors gratefully acknowledged the financial support received from Universiti Teknologi Malaysia under the Short Term Research Grant.

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Received: 1 November 2012

Accepted: 9 December 2013