

Oxidative stability study of virgin coconut oil during deep frying (Kajian kestabilan pengoksidaan minyak kelapa dara semasa penggorengan jeluk)

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Abstract

Comparative deep frying study of refined, bleached and deodorized (RBD) palm olein, RBD coconut oil and virgin coconut oil (VCO) from Malaysia and Indonesia for frying of potato chips was undertaken at 170 °C for 5 consecutive days. Several oil quality parameters were evaluated, i.e. free fatty acids content, iodine value, peroxide value, color index, viscosity, percentage of total polar materials (TPM) and other products of oxidation ($E_{1\text{cm}}^{1\%}$ at 233 and 269 nm). VCO from Malaysian Agricultural Research and Development Institute (MARDI) was found to be the least susceptible to oxidative deterioration. The oxidative stability of the different oils studied was in the order: VCO (Indonesia) < RBD palm olein < RBD coconut oil < VCO (MARDI). It was concluded that percentage of TPM and smoke point measures were not suitable as quality parameters to assess the frying performance of virgin coconut oil due to their polarity structure of medium-chain triglyceride.

Introduction

Currently, the consumption of VCO has increased significantly for food purposes and lately it is marketed as a functional food oil. Various methods have been developed to extract coconut oil, either through dry or wet processing, without exposure to high heat or chemical treatment. VCO is believed to be healthier than RBD coconut oil although the chemical properties of VCO do not vary much from the RBD coconut oil (Marina et al. 2009b). However, due to mild oil extraction, it retains most of the unsaponifiable matter in the oil, for instance, tocopherol, tocotrienol and polyphenols which are proven to be good antioxidants (Dia et al. 2005; Seneviratne et al. 2009).

In general, VCO is delicate in flavour, has unique aroma with water clear physical appearance. Numerous studies suggested that the consumption of foods containing

phenolic compounds brings significant contribution to human health (Naczki and Shahidi 2004). According to Nevin and Rajamohan (2006), VCO contains more unsaponifiable components such as vitamin E and polyphenols compared to groundnut oil and copra oil and was found to have more inhibitory effect on microsomal lipid peroxidation that prevents lipids peroxidation in both *in vitro* and *in vivo* conditions.

Deep frying is one of the most popular procedures for food preparation throughout the world. During frying, the fat or oil is kept hot (170–180 °C) for long periods and subjected to both moisture and oxygen. Complex chemical and physical changes occur under these conditions, which may reach a point where the flavour, odour, colour, nutritional value and safety of the food may be affected (Fritch 1981;

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Stevenson et al. 1984). Partial conversion of fats and oils to volatile chain-scission products, non-volatile oxidized derivatives, dimeric, polymeric, or cyclic substances may occur (Warner 2002; Kochhar and Gertz 2004). It was found that oils with high linolenic acid ($C_{18:3}$) are poor frying oils since they are rapidly deteriorated when subjected to deep frying (Warner and Mounts 1993; Warner and Knowlton 1997). Therefore, the use of oil with increased resistance to oxidation during frying would be the most appreciated.

RBD palm olein plays a major commercial role in deep frying as it matches most of the important characteristics of industrial frying oils such as high oxidative stability, high smoke point, low foaming, low melting point, bland flavour and nutritionally desirable attributes (Kochhar 2000). Frito Lay, the world's largest snack food company, used more than 90,000 tonnes of RBD palm olein annually in their operations outside the USA (Razali 2005).

Up to date, there is no report on the use of VCO as cooking oil especially as deep frying oil for foods. VCO was produced mainly as food supplement. However, there are a few cases whereby VCO was marketed as cooking oil. Therefore, the aim of this study was to investigate the oxidative stability of VCO that was subjected to continuous exposure to deep frying temperature as compared to commercial RBD palm olein, which is widely used as frying oil.

Materials and methods

Materials

Two types of VCO were used in this study: VCO obtained from MARDI and VCO purchased from Indonesia. RBD palm olein (Brand: Labour) was obtained from a local supermarket. RBD coconut oil was produced by refined, bleached and deodorized VCO from MARDI. Potatoes were bought from a local supermarket. All chemicals and solvents used were of analytical grade unless otherwise specified.

Frying experiments

Frying experiments were carried out according to the method of Che Man and Tan (1999) using four types of oil: a) VCO (MARDI); (b) VCO (Indonesia); c) RBD coconut oil (MARDI); d) RBD palm olein. Fresh potatoes (Russet var.) were peeled and sliced manually to a thickness of 2 mm. Potato slices were submerged in 0.1% (w/v) sodium chloride solution to prevent browning and slightly blotted dry with tissue paper before weighing into 100 g batches. A total of 4.5 kg oil was used in this experiment. The temperature was raised to 170 °C and maintained for the first 20 min before frying.

A batch of 100 g of potato slices was fried for 2.5 min at 17.5 min intervals for a period of 3.5 h per day with 10 batches fried per day for 5 consecutive days. During the frying period, the fryer was left uncovered. At the end of the 10th frying, the fryer was switched off and the temperature was allowed to drop to 60 °C. The oil (120 g) was collected in amber bottles and stored at -4 °C for further analysis. The lid of the fryer was then put on and the remaining oil was allowed to cool overnight. No fresh oil was added to the frying vessel on the subsequent frying days.

Analyses of oil

The quality of the fried oil was assessed and monitored across the 5 consecutive days of frying. The PORIM test methods (PORIM 1995) were used to determine the peroxide value (PV, method p2.3), free fatty acid content (FFA, method p2.5) and iodine value (IV, method p3.2). The primary and secondary products of oxidation were analysed through spectrophotometric measurement at $E_{1\text{cm}}^{1\%}$ 233 and 269 nm (method p2.15). Total polar materials (TPM) of fried oil were measured using food oil sensor (Testo 265) based on dielectric constant changes of degrading frying oils (Stier, 2004). The oil viscosity was measured using a Brookfield viscometer, DV II (Stroughton, MA, USA) with

spindle number 3 (SP63) and the shear rate was set at 20 s^{-1} . Colour index of the oil was measured according to the method of Yagmur et al. (2001). Fatty acid composition was determined by converting the fried oil to methyl esters prior to the analysis by gas chromatography. Fatty acid methyl esters (FAME) were analysed on Agilent 6890N instrument equipped with a flame ionization detector. A polar capillary column BPX70 of 0.32 mm internal diameter, 30 m length, and 0.25 μm film thickness was used to analyze the fatty acid composition. Each reported value was the mean of four analyses from two replications.

Statistical analysis

Data were statistically analysed by one-way analysis of variance procedure using SAS software (1989). Significant differences ($p < 0.05$) between means were determined by Duncan multiple range test.

Results and discussion

Physico-chemical properties of vegetable oils

Table 1 shows some physico-chemical properties of the four types of oil used in the study. RBD palm olein, RBD coconut oil and VCO (MARDI) were of good quality, as indicated by their low percentages of FFA content. VCO from Indonesia had slightly

higher percentage of FFA content (1.49%) as this unrefined oil was obtained from fermentation process (Table 1). The data obtained indicated that both types of VCO has lower smoke point (170 °C) compared to RBD palm olein and RBD coconut oil (above 200 °C), mainly due to the higher content of free short and medium-chain fatty acids in the VCO (Tables 2–3).

In terms of organoleptic assessment, VCO has the typical coconut smell, whereas RBD palm olein and RBD coconut oil were bland in flavour. The distinct coconut smell with low smoke point in VCO does not comply with the important criteria of deep frying oil. In practice, good industrial frying oil should have high smoke point (above 180 °C) with bland flavour (Kochhar 2000). Another important criterium of deep frying oil is the low content of TPM.

In this study, it was found that both VCO from Malaysia and Indonesia including RBD coconut oil had higher percentages of TPM (more than 35%) compared to RBD palm olein (12%). Such high percentage of TPM exceeded the regulatory limit imposed by European countries which stated that the value of TPM above 27% was graded as the discard point for frying oil (Mellema 2003; Sanibal and Mancini-Filho 2004). In frying operation, this oil should be discarded. However, in this case, the high percentages

Table 1. Characteristics of RBD palm olein, RBD coconut oil and VCO from MARDI and Indonesia used in frying experiments^a

	RBD palm olein	RBD coconut oil	VCO (MARDI)	VCO (Indonesia)
Peroxide value (meq/kg oil)	1.2	0.6	1.2	1.4
Iodine value (g I ₂ /100 g oil)	56.0	7.71	8.10	8.14
Free fatty acids content (%)	0.10	0.17	0.38	1.49
E ₁ ^{1%} _{1cm} at 233 nm	2.454	1.313	1.098	1.125
E ₁ ^{1%} _{1cm} at 269 nm	0.722	0.070	0.010	0.010
Colour index at 420 nm	0.622	0.080	0.020	0.020
Viscosity (centipoise)	48	40	40	40
Smoke point (°C)	220	200	172	170
% Total polar materials	12	35	36	36
Flavour	Bland	Bland	Distinct coconut smell	Distinct coconut smell (slightly sour)

^aEach value is the mean of three analyses

Table 2. Changes in iodine value, free fatty acids content, colour index, peroxide value, $E^{1\%}_{1\text{cm}}$ at 233 and 269 nm, viscosity and % total polar materials of different oils during frying

Characteristics	Day	RBD Palm Olein	RBD Coconut oil	VCO (Indonesia)	VCO (MARDI)
Iodine value (g of I ₂ / 100 g oil)	0	56.72 ± 0.32Aa	7.71 ± 0.01Da	8.14 ± 0.03Ba	8.11 ± 0.13Ca
	1	55.52 ± 0.09Ab	7.32 ± 0.01Db	7.71 ± 0.02Cb	7.82 ± 0.13Bb
	2	53.28 ± 0.15Ac	7.14 ± 0.01Dc	7.47 ± 0.01Cc	7.65 ± 0.13Bc
	3	51.61 ± 0.05Ad	6.88 ± 0.02Dd	6.99 ± 0.01Cd	7.01 ± 0.26Bd
	4	50.37 ± 0.28Ae	6.59 ± 0.03De	6.75 ± 0.01Ce	6.98 ± 0.27Be
	5	45.52 ± 0.10Af	6.38 ± 0.03Df	6.54 ± 0.02Cf	6.66 ± 0.13Bf
Free fatty acids content (%)	0	0.10 ± 0.00Df	0.17 ± 0.00Ce	1.79 ± 0.02Ad	0.38 ± 0.00Bb
	1	0.12 ± 0.00De	0.26 ± 0.01Cb	1.82 ± 0.02Ab,c,d	0.38 ± 0.00Bb
	2	0.16 ± 0.00Dd	0.28 ± 0.01Ca	1.84 ± 0.03Aa,b	0.39 ± 0.00Ba
	3	0.17 ± 0.00Dc	0.24 ± 0.01Cc	1.80 ± 0.01Ac,d	0.39 ± 0.00Ba
	4	0.20 ± 0.00Db	0.28 ± 0.00Ca	1.83 ± 0.03Aa,b,c	0.39 ± 0.00Ba
	5	0.22 ± 0.00Ca	0.20 ± 0.01Dd	1.85 ± 0.01Aa	0.39 ± 0.00Ba
Colour index	0	0.621 ± 0.00Af	0.078 ± 0.00Bf	0.020 ± 0.00Cf	0.020 ± 0.00Cf
	1	0.816 ± 0.00Ae	0.199 ± 0.00Be	0.129 ± 0.00Ce	0.126 ± 0.00De
	2	0.878 ± 0.01Ad	0.276 ± 0.00Bd	0.255 ± 0.00Cd	0.236 ± 0.00Dd
	3	0.975 ± 0.00Ac	0.383 ± 0.00Bc	0.367 ± 0.00Cc	0.343 ± 0.00Dc
	4	1.116 ± 0.00Ab	0.427 ± 0.00Ba	0.384 ± 0.00Cb	0.351 ± 0.00Db
	5	1.742 ± 0.05Aa	0.415 ± 0.00Bb	0.399 ± 0.00Ca	0.360 ± 0.00Da
Peroxide value (meq Hydroperoxide/ kg Oil)	0	2.75 ± 0.10Af	0.60 ± 0.00Df	1.50 ± 0.00Bf	1.40 ± 0.00Cf
	1	10.80 ± 0.00Be	3.40 ± 0.00Ce	16.45 ± 0.10Ae	2.60 ± 0.00De
	2	13.30 ± 0.00Bc	4.35 ± 0.10Cd	19.08 ± 0.30Ad	4.10 ± 0.00Dd
	3	14.50 ± 0.00Bb	4.70 ± 0.12Dc	21.38 ± 0.24Ac	4.90 ± 0.00Cc
	4	16.60 ± 0.00Ba	12.35 ± 0.10Ca	25.75 ± 0.10Aa	11.90 ± 0.00Da
	5	12.70 ± 0.05Bd	11.90 ± 0.12Cb	23.70 ± 0.12Ab	11.50 ± 0.00Db
$E^{1\%}_{1\text{cm}}$ at 233 nm	0	2.48 ± 0.03Af	1.31 ± 0.01Bf	1.13 ± 0.00Df	1.20 ± 0.01Cf
	1	2.72 ± 0.00Ae	1.36 ± 0.00Ce	1.38 ± 0.01Be	1.33 ± 0.00De
	2	3.37 ± 0.01Ad	1.45 ± 0.01Dd	1.76 ± 0.01Bd	1.56 ± 0.00Cd
	3	4.12 ± 0.00Ac	1.53 ± 0.00Dc	2.36 ± 0.00Bc	1.65 ± 0.00Cc
	4	4.54 ± 0.02Ab	1.64 ± 0.00Db	2.52 ± 0.00Bb	1.76 ± 0.00Cb
	5	5.26 ± 0.01Aa	1.77 ± 0.00Da	2.82 ± 0.01Ba	1.84 ± 0.01Ca
$E^{1\%}_{1\text{cm}}$ at 269 nm	0	0.10 ± 0.00Df	0.17 ± 0.00Ce	1.79 ± 0.02Ad	0.38 ± 0.00Bb
	1	0.12 ± 0.00De	0.26 ± 0.01Cb	1.82 ± 0.02Ab,c,d	0.38 ± 0.00Bb
	2	0.16 ± 0.00Dd	0.28 ± 0.01Ca	1.84 ± 0.03Aa,b	0.39 ± 0.00Ba
	3	0.17 ± 0.00Dc	0.24 ± 0.01Cc	1.80 ± 0.01Ac,d	0.39 ± 0.00Ba
	4	0.20 ± 0.00Db	0.28 ± 0.00Ca	1.83 ± 0.03Aa,b,c	0.39 ± 0.00Ba
	5	0.22 ± 0.00Ca	0.20 ± 0.01Dd	1.85 ± 0.01Aa	0.39 ± 0.00Ba
Viscosity (centipoise)	0	48 ± 0.00Ae	40 ± 0.01Bc	40 ± 0.00Bc	40 ± 0.00Bc
	1	52 ± 0.00Ad	44 ± 0.00Bb	44 ± 0.00Bb	44 ± 0.00Bb
	2	58 ± 0.00Ac	44 ± 0.00Bb	44 ± 0.00Bb	44 ± 0.00Bb
	3	62 ± 0.00Ab	48 ± 0.00Ba	48 ± 0.00Ba	48 ± 0.00Ba
	4	62 ± 0.00Ab	48 ± 0.00Ba	48 ± 0.00Ba	48 ± 0.00Ba
	5	66 ± 0.00Aa	48 ± 0.01Ba	48 ± 0.01Ba	48 ± 0.00Ba
% Total polar materials	0	12.00 ± 0.00Ce	35.50 ± 0.41Bc	36.00 ± 0.01Ae	36.00 ± 0.00Ae
	1	13.00 ± 0.00Dd	35.00 ± 0.01Cd	37.00 ± 0.02Ad	36.00 ± 0.00Be
	2	13.50 ± 0.00Dc	35.88 ± 0.25Cb	38.63 ± 0.25Ac	37.00 ± 0.00Bd
	3	13.50 ± 0.00Dc	36.00 ± 0.00Cb	39.75 ± 0.29Ab	38.00 ± 0.00Bc
	4	14.00 ± 0.00Db	36.00 ± 0.00Cb	40.00 ± 0.00Ab	39.00 ± 0.00Bb
	5	16.00 ± 0.00Da	37.00 ± 0.01Ca	40.63 ± 0.75Aa	40.00 ± 0.00Ba

Each value represents the mean ± standard deviation of 4 analyses from 2 replications. Means within row with different big letters are significantly ($p < 0.05$) different. Means within each column with different small letters are significantly ($p < 0.05$) different.

Table 3. Changes in fatty acid composition for different oils during frying

Frying oil	Day	Fatty acids (%)									
		C _{6:0}	C _{8:0}	C _{10:0}	C _{12:0}	C _{14:0}	C _{16:0}	C _{18:0}	C _{18:1}	C _{18:2}	C _{18:3}
RBD palm olein	0	–	–	–	0.22	1.18	41.05	4.20	42.44	10.56	0.35
	1	–	–	–	0.41	1.55	42.44	4.51	42.18	9.41	0.30
	2	–	–	–	0.32	1.33	41.48	4.34	44.19	8.07	0.27
	3	–	–	–	0.31	1.21	42.5	4.65	44.28	6.86	0.19
	4	–	–	–	0.27	1.46	43.79	4.55	43.64	6.14	0.15
	5	–	–	–	0.36	1.52	43.75	4.72	43.87	5.66	0.12
RBD coconut oil	0	0.98	9.24	7.12	49.74	18.06	8.15	2.31	3.98	0.42	–
	1	0.95	9.18	7.14	50.68	17.46	8.07	2.28	3.88	0.36	–
	2	0.89	9.25	7.15	49.87	17.91	8.18	2.35	4.11	0.29	–
	3	0.92	9.27	6.97	50.65	17.47	8.12	2.31	4.03	0.26	–
	4	0.86	9.18	7.05	49.92	18.09	8.22	2.37	3.96	0.25	–
	5	0.79	9.21	7.17	50.98	17.08	8.23	2.35	3.99	0.20	–
VCO (Indonesia)	0	1.52	9.96	7.14	49.53	17.89	7.02	2.25	4.07	0.62	–
	1	1.38	9.89	7.12	49.46	18.21	7.00	2.27	4.11	0.56	–
	2	1.31	9.92	7.15	49.65	18.00	7.15	2.33	4.04	0.45	–
	3	1.42	9.75	7.09	49.55	18.19	7.13	2.31	4.18	0.38	–
	4	1.35	9.64	7.12	49.42	18.49	7.28	2.31	4.05	0.34	–
	5	1.30	9.82	7.08	49.35	18.46	7.35	2.34	4.04	0.26	–
VCO (MARDI)	0	1.34	9.87	6.87	49.92	17.96	6.95	2.39	4.14	0.57	–
	1	1.32	9.91	6.86	50.16	17.68	7.01	2.37	4.16	0.53	–
	2	1.34	9.85	6.87	50.05	17.92	6.98	2.42	4.09	0.48	–
	3	1.42	9.78	6.92	49.65	17.95	6.94	2.41	4.51	0.42	–
	4	1.38	9.86	6.92	50.17	17.85	6.94	2.37	4.12	0.39	–
	5	1.47	9.94	6.72	49.99	18.04	6.92	2.32	4.25	0.35	–

Each value is the mean of 4 analyses from 2 replications

of TPM in VCO and RBD coconut oil were due to the higher diglycerides content (>4%) (Dayrit et al. 2008) and polarity structure of medium-chain fatty acids (more than 65%) (Marina et al. 2009a). These factors are the major contribution of polar materials in coconut oil compared to RBD palm olein. Other polar compounds like glycolipids and phospholipids also contribute to the high percentage of TPM in the coconut oil. Although the data from *Table 1* showed that VCO does not fulfil some of the frying oil criteria requirement, but coconut oil may have excellent oxidative stability at high temperature due to high content of saturated fatty acids (>95%). Furthermore, this oil has a distinct coconut smell which may give good flavour to the fried food.

Changes in iodine value (IV), free fatty acid (FFA) content and colour indices

The changes in IV, FFA content and colour indices of the four different frying oils during 5 consecutive days of frying are shown in *Table 2*. Iodine Value indicates the degree of fatty acids unsaturation in oils and it also indicates the liquidity of the oil at the specific temperature. Palm oil (IV 52) and palm olein (IV 56–60) are commonly used as frying oils in food industry as these two oils match most of the important criteria as frying oil. In general, the IV for all types of oil decreased significantly ($p < 0.05$) over 5 consecutive frying days. A decrease in IV showed that the double bond of unsaturated fatty acids were damaged by oxidation and polymerization (Cuesta et al. 1991). RBD palm olein showed the higher changes of

IV during 5 frying days, which was 11.2 g of I₂/100 g of oil as compared to both RBD coconut oil and VCO. Higher amounts of linoleic and linolenic acids (C_{18:2} and C_{18:3}, polyunsaturated fatty acids) in RBD palm olein (Table 3) caused this oil to be more prone to oxidative deterioration, and resulted in greater loss of IV than the coconut oil. Compared to RBD palm olein, it was noted that the IV of both VCO and RBD coconut oil only showed a small decrease after 5 consecutive frying days, indicating that coconut oil was less susceptible to oxidation.

FFA content is the most common indicator of oil quality in food industry. It is a measure of the acidic components in the oil that contributes to the development of off-flavour in products. From the results obtained, the FFA content was observed to significantly increase indicating the oil degrades during successive frying (Table 2). However, small changes in the FFA content did not affect the oil quality. This phenomenon was the same as reported by other researchers (Che Man and Tan 1999; Chu et al. 2001; Warner and Gupta 2005) whereby only small changes in FFA content was observed throughout the frying period using palm olein.

It was reported that the FFA content is not a reliable measurement of oil deterioration (Fritch 1981). Fritch's study concluded that the value of FFA content as a measurement of frying oil degradation level is controversial as FFA are volatile and can be lost via steam distillation. Although FFA content is not an important parameter for comparing oil stability, it could be used as an indicator to show whether the frying temperature was under control or not. The formation of FFA can be attributed by oil hydrolysis during frying and the presence of carboxylic groups in polymeric products of frying oil (Tyagi and Vasishtha 1996).

Basically, RBD coconut oil and VCO showed lower FFA content increment as compared to RBD palm olein. The higher value of FFA content in VCO (Indonesia) during frying could be due to the higher

initial concentration of FFA (1.79%), which tends to catalyse the hydrolysis reaction. In summary, the FFA content of all oil types after 5 days of frying were less than 2%, below the discard points of 2.0–5%.

Product colour appearance is an easy way to determine the discard point of oil. In practice, the oils are rejected when the fried food products show dark appearance even though other oil quality measures have not reached the discard point yet. In this study, both types of VCO had lower colour index changes, which was water clear compared to RBD palm olein and RBD coconut oil (light yellow). In general, RBD palm olein > RBD coconut oil > VCO (Indonesia) > VCO (MARDI) showed a marked increase in colour index at the end of frying operations, reflecting an overall chemical degradation and polymerization (Table 2).

It was most probably due to the oxidation reaction that resulted in the generation of hydroperoxides, conjugated dienoic acids, epoxides, hydroxides and ketones. These compounds could undergo further oxidation or may remain in the triglyceride molecule and cross-linked with each other, leading to the formation of dimeric and higher polymeric triglycerides (White 1991), causing a darker colour. In addition, the colour of frying oil could be darkened due to the formation of browning pigments from the potato chips (Fritch 1981; Augustin et al. 1987). Of all the oils used, VCO from MARDI showed the smallest change in colour index compared to the other oils.

Changes in peroxide value and other products of oxidation ($E_{1cm}^{1\%}$ at 233 and 269 nm)

The primary products of lipid oxidation are hydroperoxides, generally referred as peroxide value (PV). PV is a good indicator of lipid oxidation, but its use was limited to the initial stages of oxidation (Gray 1978). Initially, the PV of all the oils used increased until day 4 of frying and then fell slightly on the last frying day (Table 2),

mainly due to the decomposition of the peroxides products to produce carbonyl and aldehydic compounds under deep frying operations (Makhoul et al. 2006).

VCO from MARDI had similar results with RBD coconut oil. Small changes in PV only occurred in RBD palm olein. VCO from MARDI showed the highest thermal stability against peroxide formation due to the presence of tocopherols (Dia et al. 2005; Seneviratne et al. 2009). However, VCO from Indonesia showed the highest PV value throughout the frying process. The high moisture content in this VCO could promote the formation of peroxide product (Akinoso et al. 2010). The primary oxidation products, mainly hydroperoxides, are unstable under deep frying conditions. These products readily decomposed into mixtures of volatile aldehyde compounds. Thus, PV may not be able to indicate the actual extent of oil deterioration (Fritch 1981; Melton et al. 1994). Anisidine value (AV), which indicate secondary oxidations, is a more reliable quality measurement compared to PV. However, this test was not carried out in this study.

The changes in $E_{1\text{cm}}^{1\%}$ at 233 and 269 nm can be used to indicate primary and secondary oxidation products besides PV and AV tests. Conjugated dienes formed as a result of primary oxidation showed an absorption band at 233 nm, while secondary oxidation products, particularly ethylenic diketones, showed an absorption band at 269 nm (Gray 1978). Therefore, the changes in $E_{1\text{cm}}^{1\%}$ at 233 and 269 nm of a given oil can be used as a relative measurement of oxidation. In general, all the oils showed a significant increment ($p < 0.05$) in both $E_{1\text{cm}}^{1\%}$ at 233 and 269 nm throughout the frying days.

The formation of conjugated dienes during frying was proportional to the linoleic acid content of the oil (Smith et al. 2007). This phenomenon was the same as reported by Che Man and Tan (1999) and Chu et al. (2001). Coconut oil, which has lower content of polyunsaturated fatty acids,

undergoes lower conjugated diene formation, showing that it is more resistant to thermal deterioration than RBD palm olein. The higher changes of $E_{1\text{cm}}^{1\%}$ at 233 nm observed in RBD palm olein were mainly due to its higher content of $C_{18:2}$ (Table 3), resulting in higher oxidation of unsaturated fatty acids into oxidation products.

Changes in viscosity and percentage of TPM

The changes in viscosity and percentage of TPM of all oil types are presented in Table 2. As the oxidation process accelerated by heat proceeded, the viscosity value of oil samples also increased with frying periods (Koh et al. 2011). RBD palm olein which contains the highest level of long-chain fatty acids ($C_{14:0} - C_{18:0}$) had higher viscosity initially. During the 5 days of frying, there was a marked increased in viscosity value for all the oils. The oil viscosity is directly related to degradation products which are mainly polymer products formed during frying.

The results obtained from Table 2 clearly indicated the higher deterioration effect of oxidation and polymerization of RBD palm olein, which resulted in the formation of higher molecular weight compounds compared to the different types of coconut oils. Majority of the dimeric and polymeric compounds are intermolecularly formed from carbon to carbon linkages and only minor dimers are formed by carbon-oxygen-carbon bridges, and these compounds will continue to cross-link as the oils are continuously exposed to high temperature (Warner 2002; Kochhar and Gertz 2004).

Polar materials are composed of degradation products, non-volatile oxidized derivatives, polymeric and cyclic substances produced during frying of foodstuffs or heating. Non-polar compounds are mostly unaltered triglycerides. Percentage of TPM is of major importance as a quality parameter because of a regulatory limit of 25–27% which has been officially adopted

in a number of countries (Mellema 2003; Sanibal and Mancini-Filho 2004).

In this study, a food oil sensor (Testo 265) was used to measure the percentage of TPM present in the frying oil. Food oil sensor is a simple and fast method to determine percentage of TPM compared to conventional preparative column chromatography by monitoring the changes in the dielectric constant of degraded frying oils (Hein et al. 1998). It is widely used in the food industry to monitor the frying oil quality as it is easily handled by any food operator.

In general, coconut oil consists of more than 65% medium-chain fatty acids which are relatively more polar than long chain fatty acids (Marina et al. 2009a). Therefore, their initial value of TPM was much higher compared to other oils as shown in *Table 2*. Although the percentage of TPM may not be a good oil quality parameter, the changes in the TPM throughout the 5 consecutive frying days can be used to measure the degree of oil degradation for coconut oil. Generally, all types of coconut oil showed a small increment in percentage of TPM as opposed to RBD palm olein throughout the frying periods, indicating better oxidative stability.

In summary, VCO from MARDI had the highest oxidation stability as opposed to other oils under continuous exposure to high temperature for 5 consecutive frying periods. Although the sensory evaluation on fried potato chips was not conducted in this study, we observed that all the potato chips fried either with RBD palm olein or various types of coconut oil showed no differences in terms of odour and crispiness.

Conclusion

The low degree of unsaturated fatty acids content with the presence of natural antioxidants in VCO indicated the highest resistance to oxidative stability during deep frying. Of all oils used, VCO from MARDI showed the least susceptible to oxidation compared to other oils. As a summary, the

percentage of TPM and smoke point were unsuitable oil quality parameters to assess the frying performance of VCO.

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References

- Akinoso, R., Aboaba, S.A. and Olayanju, T.M.A. (2010). Effects of moisture content and heat treatment on peroxide value and oxidative stability of un-refined sesame oil. *Afr. J. Food Nutr. Sci.* 10: 4268–4285
- Augustin, M.A., Lee, K.H. and Yan, K.T. (1987). Comparison of the frying performance of market samples of palm olein, corn oil and soya oil in Malaysia. *Pertanika* 10: 295–304
- Che Man, Y.B. and Tan, C.P. (1999). Effects of natural and synthetic antioxidants on changes in refined, bleached and deodorised palm olein during deep-fat frying of potato chips. *J. Am. Oil Chem. Soc.* 76: 331–339
- Chu, B.S., Ghazali, H.M., Lai, O.M., Che Man, Y.B., Yusoff, S. and Yusoff, M.S.A. (2001). Performance of a lipase-catalyzed transesterified palm kernel olein and palm stearin blend in frying banana chips. *Food Chem.* 74: 21–33
- Cuesta, C., Sanchez-Muniz, F.J. and Hernandez, I. (1991). Evaluation of nonpolar methyl esters by column and gas chromatography for the assessment of used frying olive oils. *J. Am. Oil Chem. Soc.* 58: 6–12
- Dayrit, F.M., Buenafe, O.E.M., Chainani, E.T. and Vera, I.M.S.D. (2008). Analysis of monoglycerides, diglycerides, sterols and free fatty acids in coconut (*Cocos nucifera* L.) oil by ³¹P NMR spectroscopy. *J. Agric. Food Chem.* 56: 5765–5769
- Dia, V.P., Garcia, V.V., Mabesa, R.C. and Tecson-Mendoza, E.M. (2005). Comparative physicochemical characteristics of virgin coconut oil produced by different methods. *Philippine Agr. Sci.* 88: 462–475
- Fritch, C.W. (1981). Measurements of frying fat deterioration: A brief review. *J. Am. Oil Chem. Soc.* 58: 272–274
- Gray, J.I. (1978). Measurement of lipid oxidation: a review. *J. Am. Oil Chem. Soc.* 55: 539–546

- Hein, M., Henning, H. and Isengard, H. (1998). Determination of total polar parts with new methods for the quality survey of frying fats and oils. *Talanta* 47: 447–454
- Kochhar, S.P. (2000). Stable and healthful frying oil for the 21st century. *INFORM* 11: 642–647
- Kochhar, S.P. and Gertz, C. (2004). New theoretical and practical aspects of the frying process. *Eur. J. Lipid Sci. and Technol.* 106: 722–727
- Koh, S.P., Arifin, N., Tan, C.P., Yusoff, M.S.A., Long, K. and Lai, O.M. (2011). Deep frying performance of enzymatically synthesized palm-based medium- and long-chain triacylglycerols (MLCT) oil blends. *Food Bioprocess Technol.* 4: 124–135
- Makhoul, H., Ghaddar, T. and Toufeili, I. (2006). Identification of some rancidity measures at the end of the shelf life of sunflower. *Eur. J. Lipid Sci. Technol.* 108: 143–148
- Marina, A.M., Che Man, Y.B. and Amin, I. (2009a). Virgin coconut oil: emerging functional food oil. *Trends Food Sci. Tech.* 20: 481–487
- Marina, A.M., Che Man, Y.B., Nazimah, S.A.H. and Amin, I. (2009b). Chemical properties of virgin coconut oil. *J. Am. Oil Chem. Soc.* 86: 301–307
- Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends Food Sci. Tech.* 14: 364–373
- Melton, S.L., Jafar, S., Sykes, D. and Trigiano, M.K. (1994). Review of stability measurements for frying oils and fried food flavour. *J. Am. Oil Chem. Soc.* 71: 1301–1308
- Naczki, M. and Shahidi, F. (2004). Extraction and analysis of phenolics in food. *J. Chrom. A.* 1054: 95–111
- Nevin, K. G. and Rajamohan, T. (2006). Virgin coconut oil supplemented diet increases the antioxidant status in rats. *Food Chem.* 99: 260–266
- PORIM (1995). *PORIM Test Methods*. Palm Oil Research Institute of Malaysia, Ministry of Primary Industries, Malaysia
- Razali, I. (2005). Palm oil and palm olein frying applications. *Asia Pacific J. Clin. Nutr.* 14: 414–419
- Sanibal, E.A.A. and Mancini-Filho, J. (2004). Frying oil and fat quality measured by chemical, physical and test kit analyses. *J. Am. Oil Chem. Soc.* 81: 847–852
- Seneviratne, K.N., Hapuarachchi, C.D. and Ekanayake, S. (2009). Comparison of the phenolic-dependent antioxidant properties of coconut oil extracted under cold and hot conditions. *Food Chem.* 114: 1444–1449
- Smith, S.A., King, R.E. and Min, D.B. (2007). Oxidative and thermal stabilities of genetically modified high oleic sunflower oil. *Food Chem.* 102: 1208–1213
- Stevenson, S.G., Vaisey-Genser, M. and Eakin, N.A.M. (1984). Quality control in the use of deep frying oils. *J. Am. Oil Chem. Soc.* 61: 1101–1108
- Stier, R.F. (2004). Tests to monitor quality of deep-frying fats and oils. *Eur. J. Lipid Sci. Technol.* 106: 766–771
- Tyagi, V. K. and Vasishtha, A.K. (1996). Changes in characteristics and composition of oils during deep-fat frying. *J. Am. Oil Chem. Soc.* 73: 499–506
- Warner, K. (2002). Chemistry of frying oils. In: *Food lipids* (Akoh, C.C. and Min, D.B., eds.), p. 205–221. New York: Marcel Dekker
- Warner, K. and Gupta, M. (2005). Potato chip quality and frying oil stability of high oleic acid soybean oil. *J. Food Sci.* 70: 395–400
- Warner, K., and Knowlton, S. (1997). Frying quality and oxidative stability of high-oleic corn oils. *J. Am. Oil Chem. Soc.* 74: 1317–1322
- Warner, K. and Mounts, T.L. (1993). Frying stability of soyabean and canola oils with modified fatty acids compositions. *J. Am. Oil Chem. Soc.* 70: 983–988
- White, P.J. (1991). Methods for measuring changes in deep-fat frying. *Food Tech.* 45: 75–80
- Yaghmur, A., Aserin, A., Mizrahi, Y., Nerd, A. and Garti, N. (2001). Evaluation of argan oil for deep-fat frying. *Food Sci. Tech.* 34: 124–130

Abstrak

Kajian perbandingan penggorengan jeluk kerepek kentang menggunakan minyak sawit bertapis yang dinyah warna dan bau (RBD), minyak kelapa RBD dan minyak kelapa dara (VCO) dari Malaysia dan Indonesia telah dijalankan pada suhu 170 °C selama 5 hari berturut-turut. Beberapa parameter telah diuji untuk mengukur kualiti minyak iaitu kandungan asid lemak bebas, nilai iodin, nilai peroksida, indeks warna, kelikatan, peratus jumlah bahan polar (TPM) dan produk pengoksidaan ($E_{1\text{cm}}^{1\%}$ pada 233 dan 269 nm) yang lain. VCO dari MARDI didapati paling kurang terjejas akibat daripada tindak balas pengoksidaan. Turutan minyak yang stabil daripada tindak balas pengoksidaan adalah seperti yang berikut: VCO (Indonesia) < minyak sawit RBD < minyak kelapa RBD < VCO (MARDI). Pengukuran peratus TPM dan titik asap didapati tidak sesuai digunakan sebagai parameter untuk menilai kualiti minyak kelapa dara semasa penggorengan kerana sifat semula jadi minyak yang mempunyai struktur kekutuban trigliserida berantai sederhana.