FOOD

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# Enhanced natural antioxidant compounds in red palm olein-based shortening developed for sandwich cookie cream

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## Abstract

Red palm olein (RPOL) is a premium palm-based product which is underutilized in the local market due to the lack of consumers' awareness of its nutritional benefits. It was blended with palm oil (PO) and palm stearin (PS) at different ratios 0:50:50, 5:45:50, and 10:40:50 of RPO:PO:PS. These fat blends were developed to produce shortenings with improved antioxidant compounds meant for sandwich cookies cream (SCC). The RPOL exhibited greater liquid-like properties which contributed to softer shortenings yet with significant solid fat content at 25°C (33.58-34.71%) and 37°C (10.25-10.84%), besides similar in melting point (47.80-47.93°C) with the shortening without RPOL (47.93±0.12° C). As the RPOL increased from 0%, 5%, and 10% (w/w), a significant ($p<0.05$) increase took place in the shortenings' carotene (18.47±0.42 ppm, 50.32±7.94 ppm, 84.75±1.22 ppm, respectively) and tocopherol (142.67±2.08 ppm, 140.33±1.53 ppm, 150.33±3.06 ppm, respectively) content. Shortening with 5% (w/w) RPOL exhibited a greater ß' polymorphic form than that of 10% (w/w) RPOL which contributed to its better creaming performance for a sandwich cookie cream.

## 1. Introduction

Sandwich cookie cream (SCC), also known as biscuit cream, cookie filler, or cream filling, is a confectionery product applied between two pieces of cookies and enhances the cookies' palatability. It is made of 20-40% fat, besides powdered sugar, milk powder, and flavouring essence (Mat Yusoff *et al.,* 2013). The fat portion plays an important role in developing good SCC quality with firm structure at room temperature, besides creamy texture, smooth mouth-feel, and quick setting (Kanagaratnam *et al.*, 2009; Mat Yusoff *et al.*, 2013). Despite the functionality of fat in an SCC, it is normally composed of highly saturated fat which is undesirable nowadays, as it reduced the fat plasticity (Mat Sahri and Mat Dian, 2011). Therefore, many studies reformulated an SCC, either by replacing the fat portion with other ingredients or by modifying the fat portion into that of less saturated fat. In a study done by Tanti *et al.* (2016), the use of structured oil (i.e. organogels) provided better structure and texture to an SCC. Moreover, according to Hadnadev *et al.* (2014), replacing fat with maltodextrin gel resulted in an SCC with increased hardness, enhanced colour, and low calory. Many former studies had also improved the physicochemical properties, functionality, and plasticity of the fats for an SCC in terms of fatty acid composition, solid fat content (SFC), slip melting point, and texture by using blends of vegetable oils and fats from different sources (Kanagaratnam *et al.,* 2009; Mat Yusoff *et al.,* 2013; Cruz Serna *et al.,* 2014).

Palm-based fats and oils are famous alternatives in developing shortening for confectionery and bakery products such as spread, pastry, ice cream, cheese, and peanut butter (Berger and Idris, 2005). The wide use of

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these oils was due to their various fractions exhibiting assorted physicochemical characteristics which can be modified and tailored into food products of desirable properties without producing trans-fatty acid (Mat Sahri and Mat Dian, 2011; Saghafi *et al.*, 2018). In the case of SCC, Mat Yusoff *et al.* (2013) blended lauric fats and palm mid fraction which was proved to provide a similar SFC profile with those of selected commercial SCC samples. Besides, Kanagaratnam *et al.* (2009) had developed palm-based shortening for SCC formulation consisting of hard (palm stearin), medium-hard (palm oil), and soft (palm olein) fractions at suggested levels of 10-15%, 60-70%, and 15-20%, respectively. In another study, Cruz Serna *et al.* (2014) blended palm kernel oil and palm stearin to produce a fat portion exhibiting a wide variation of fatty acid composition. This property was important in providing the desirable SFC profile of an SCC which further improved the palate fusion and enhanced the fat plasticity. Kanagaratnam *et al.* (2009) highlighted the importance of the SFC profile which critically affects the fat's behaviour during processing, eating, and storing of an SCC product.

Another type of palm-based oil of great interest nowadays is red palm olein (RPOL) which is the olein fraction of red palm oil. Nagendran *et al.* (2000) summarized the nutritional properties of these two oils which were approximately similar to each other. The ratio between saturated and unsaturated fatty acids in RPOL was equally balanced (50:50 w/w) which is beneficial in improving human health status, especially those related to atherosclerosis, such as reducing serum cholesterol concentration and plaque deposition in the blood (Edem and Akpanabiatu, 2006; Dauqan *et al.*, 2011). Furthermore, RPOL is rich in beneficial compounds mainly carotenoids, tocopherols, and tocotrienols (Nagendran *et al.*, 2000; Kumar *et al.*, 2016). These compounds act as natural antioxidants which are useful in reducing oxidative stress and halt free radical release in oil, therefore decelerating the oxidation process (Ayu *et al.*, 2016; Kumar *et al.*, 2016). Upon consumption, these compounds were beneficial in reducing the oxidative status in the human cell membrane, especially adult patients with cardiovascular disease, cancer, and other chronic diseases (Oguntibeju *et al.*, 2009), besides being useful in combating vitamin A-deficiency among children and breastfeeding mother in developing countries (Manorama, 2014). Shortenings based on RPOL with improved fat plasticity and functionality had successfully been developed for bread (Al-Saqer *et al.*, 2004), cookies (El-Hadad *et al.*, 2010), and chocolate spread (Kumar *et al.*, 2016). These studies proved that the desirable physicochemical properties of a shortening are attainable upon the incorporation of RPOL in the fat blend at a suitable ratio.

The potential of RPOL in enhancing the nutritional and antioxidative properties of food products were well discovered. Therefore, this study aimed to include RPOL in a shortening formulation meant for an SCC product which is commonly consumed among kids, teenagers, and adults. The incorporation of RPOL can potentially boost the antioxidative properties of the shortening and the developed SCC whilst incorporating the vitamins in the consumer diet.

## 2. Material and methods

### 2.1 Materials

Red palm olein (RPOL), palm oil (PO), and palm stearin (PS) were provided by Sime Darby Oils Langat Refinery Sdn Bhd, Selangor, Malaysia. A commercial shortening sample (Commercial X) was purchased from the local supermarket. Castor sugar was purchased in a local hypermarket in Telok Panglima Garang, Selangor. The chemicals used were sodium methoxide, n-heptane, iso-octane, and iso-propanol (Merck, Darmstadt, Germany), N-Hexane (Macron Fine Chemicals, Phillipsburg, New Jersey, USA), and standard reagents of α- tocopherol, and α-, β-, δ-, and γ- tocotrienol (Davos Chemical Corp, New Jersey, USA).

### 2.2 Preparation of red palm olein based-shortening

The blends of RPOL:PO:PS were prepared into shortenings at different ratios of 0:50:50 (control sample, SH-0), 5:45:50 (SH-5) and 10:40:50 (SH-10) which were based on the method suggested by Osman and Nor Aini (1999) with minor modification. Each blend of 1.5 kg was melted and homogenized by using Silverson Mixer Emulsifier (England, UK) at low speed (900-1200 rpm) for 5 min, followed by higher speed (25,000 rpm) until the fat started to crystallize. Along the crystallization process, the blends were immersed in the water bath at 20°C while continuously being scrapped and folded thoroughly to avoid the bottom part from hardening. The process ended as the blends formed into a semi-solid state. The shortenings were further incubated at 20°C in New Brunswick Scientific Incubator (New Jersey, USA) for 48 hrs and stored at room temperature (27±3°C) prior to analysis. Each shortening sample was prepared in two independent batches, and all analysis methods were performed on each shortening batch in triplicate.

### 2.3 Determination of fatty acid composition

Fatty acid composition of the fat was determined according to AOCS Official Method Ce 1a-13 (AOCS, 2003) using GC-FID (Model: Agilent 7890A, USA). Fatty acids were first methylated into fatty acid methyl esters (FAME) prior to injection into an SP-2560 (Supelco, Pennsylvania, USA) capillary column (100m x

0.25 mm i.d. × 0.25 μm). The oven temperature was programmed at 100°C for 5 mins, increased to 200°C at a rate of 20°C/min, and finally increased to 240°C at a rate of 10°C /min and hold for 3 mins.

## 2.4 Determination of iodine value

The iodine value (IV) of the shortenings was theoretically calculated from their major fatty acids (C16, C18:1, C18:2, and C18:3) present according to the method described by Kumar *et al.* (2016) based on the following formula:

$$IV = [C16\% \times 0.95) + (C18:1\% \times 0.86) + (C18:2 \times 1.732) + (C18:3\% \times 2.615)]$$

## 2.5 Determination of slip melting point

The slip melting point (SMP) of the shortenings was determined based on the Malaysian Palm Oil Board (MPOB) Test Method (2005).

## 2.6 Determination of solid fat content

The solid fat content (SFC) of the shortenings was determined according to the MPOB Test Method (2005) at 15, 20, 25, 30, 35, 37, 40, 45, and 50°C. The SFC values were obtained by using Bruker Minispec PC 120 Pulse Nuclear Magnetic Resonance (NMR) analyser (Karlsruhe, Germany).

## 2.7 Determination of thermal profile

The thermal profiles of the shortenings were determined according to the AOCS official method Cj1-94 (AOCS, 2003). The thermograms of the samples were analysed by PerkinElmer Differential Scanning Calorimeter (DSC) (Norwalk, USA). Each sample was subjected to 60°C isotherms for 5 mins, cooled to -80°C at 5°C/min, and held for 5 mins for crystallization. The sample was further subjected to heating from -80°C to 60°C/min at the same rate. The data obtained was analysed and plotted by using Pyris Software 8.0, PerkinElmer Corporation (Norwalk, USA).

## 2.8 Determination of carotene content

Carotene content of the shortenings was determined by using the MPOB Test Method (2005). The carotene content was calculated by using the following formula:

Carotene content (ppm) = (V × AB × 10000) / (W × 2610)

Where V is the volume of iso-octane used; AB is the absorbance reading of the shortenings; W is the weight of the shortenings used, and 2610 is the β-carotene extinction coefficient in petroleum ether.

## 2.9 Determination of tocopherols and tocotrienols contents

Vitamin E content was analysed using high performance liquid chromatography (HPLC) according to MPOB Test Method (2005). Approximately 0.02 g of melted sample was dissolved in 5 mL of n-heptane. Each mixture (20 μL) was injected into Agilent 1100 series HPLC equipped with a fluorescence detector (Agilent, USA). Emission and excitation wavelength was set at 330 nm and 290 nm, respectively. The sample was eluted using mobile consisting of heptane and isopropanol at a ratio of 99.5:0.5 (v/v) with a flow rate of 1.4 mL/min and a running time of 30 mins. The temperature of the column was set at 35°C. The column used was Luna® 5 μm silica of 250 mm in length × 4.6 mm in diameter (Phenomenex, California, United State). The α-tocopherol, α-, β, γ- and δ -tocotrienols were identified by comparing with 95.5% tocols standard (Darvo Life Science, KLK OLEO).

## 2.10 Determination of hardness

The hardness of the shortenings was determined according to the method done by Mat Yusoff *et al.* (2013) by using a texture analyser (Texture Analyzer TA -XT2i, New York, USA). The shortening was spread into a cup and pressed by a P10 probe (10 mm in diameter) to 50% of the shortening's height at room temperature. The distance between the sample and the probe was kept at 3 mm with a trigger force of 5 g for 5 s.

## 2.11 Determination of colour properties

The colour of the shortenings was determined based on the method described by Hadnadev *et al.* (2014) by using Minolta CR-300 colourimeter (Konica Minolta Sensing Inc., Osaka, Japan) which is a handheld tristimulus colourimeter. The measurement was performed above the white smooth surface to reduce external lightness interference and was reported based on the CIE Lab colour system which consists of L* (lightness), a* (redness to greenness), and b* (yellowness to blueness) values.

## 2.12 Determination of polymorphic forms

The polymorphic forms of the shortenings were determined by X-ray diffraction based on the method done by Buitimea-Cantúa *et a1.* (2017) using an X-ray diffractometer (Rigaku, Tokyo, Japan) equipped with a DSC III calorimeter (Rigaku, Tokyo, Japan). The shortenings were stored at 5°C for stabilization purposes prior to analysis. The measurement was performed by applying X-rays to the sample using the reflection method in a diffraction-angle range of 1–30°, with Cu-Ka radiation. The X-ray data were processed by a

computer programmed for calculating the absorption intensity, background intensity, and peak width in degree for each crystalline form where the polymorphic forms were acquired. The intensity of β′ was calculated from 3.8, 4.2, and 4.4 Å, while the intensity of β form was calculated from 4.6 Å. The other little peaks were considered insignificant and therefore were ignored.

## 2.13 Determination of creaming performance

The creaming test was carried out in order to identify the ability of the shortenings to trap or lose air according to the method done by Nor Aini *et al.* (1989) with minor alterations. A total of 50 g of each shortening and castor sugar were mixed and beaten in a bowl by using Hobart food mixer (Ohio, USA). The 'creaming power' or creaming performance of the shortenings was determined at every 5 mins interval until the 35th min by using a weighted steel cup, and was calculated as follows:

Creaming performance = (volume of shortening/weight of shortening) × 100

## 2.14 Statistical *analysis*

All results were expressed as mean±standard deviation (n = 6) by using MINITABTM Statistical Software (MINITAB® 14.12.0, New York, USA). One-way ANOVA and Tukey's multiple comparison test at 95% confidence level was used to determine significant differences between different sets of data.

## 3. Results and discussion

### 3.1 Physicochemical properties of shortenings with different fat blends

Table 1 illustrates the fatty acid composition (FAC) of native fats (RPOL, PO, PS) used in preparing the shortenings, the RPOL-based shortenings (SH-0, SH-5, and SH-10), and the Commercial X. In all native fats, the dominant fatty acids were C16:0 (35.70-56.20%) and C18:1 (29.92-44.99%). Specifically, the RPOL was significantly ($p < 0.05$) lowest in C16:0 (35.70±0.55%) and was significantly ($p < 0.05$) highest in C18:1 (44.99±1.12%), C18:2 (12.24±0.22%), and C18:3 (0.33±0.01%) which contributed to its significantly ($p < 0.05$) highest mono- (MUFA) and poly- (PUFA) unsaturated fatty acid contents as compared to both PO and PS. These compositions also contributed to significantly ($p < 0.05$) highest IV (60.91±0.62) and lowest SMP (20.20±0.20°C) in the RPOL (Table 1). Additionally, the RPOL exhibited sharp SFC profile with nearly 0% SFC at 20°C (Figure 1) which was reflected by its significantly smaller ($p < 0.05$) melting range (35.80±0.28°C) in comparison with PO (52.40±9.61°C) and PS (68.67±2.45°C) (Table 2). It was also shown in Table 2 that the RPOL needed much lower temperature ($T_f$, -28.80±0.00°C) to completely freeze than that of PO ($T_f$, -6.87±0.47°C) and PS ($T_f$, -7.71±4.11°C), despite starting to crystallize at insignificantly ($p > 0.05$) different temperatures ($T_0$, 30.91-37.55°C). These results highlighted the greater liquid-like property of RPOL as compared to PO and PS, and justified the need to blend it with other types of oils or fats in order to obtain the

Table 1. Fatty acid composition, iodine value, and slip melting point of native fats, RPOL-based shortenings, and Commercial X

| Physicochemical properties | | Native fats | | | Shortening | | | Commercial X |
|---|---|---|---|---|---|---|---|---|
| | | RPOL | PO | PS | SH-0 | SH-5 | SH-10 | |
| Fatty acid composition | C12:0 | 0.33±0.01[a] | 0.23±0.00[b] | 0.03±0.00[c] | 0.12±0.11[A] | 0.20±0.00[A] | 0.21±0.00[A] | 0.19±0.02[A] |
| | C14:0 | 1.03±0.01[c] | 1.11±0.01[b] | 1.28±0.01[a] | 1.20±0.02[A] | 1.19±0.00[A] | 1.18±0.01[A] | 1.90±1.04[A] |
| | C16:0 | 35.70±0.55[c] | 43.02±0.06[b] | 56.20±0.01[a] | 49.40±0.07[AB] | 49.23±0.01[B] | 48.63±0.02[B] | 50.20±0.38[A] |
| | C16:1 | 0.20±0.00[a] | 0.17±0.00[b] | 0.11±0.00[c] | 0.14±0.00[A] | 0.14±0.00[A] | 0.14±0.00[A] | 0.16±0.04[A] |
| | C18:0 | 3.80±0.01[c] | 4.06±0.00[b] | 4.76±0.01[a] | 4.40±0.01[B] | 4.40±0.00[B] | 4.36±0.00[B] | 4.70±0.07[A] |
| | C18:1 | 45.17±1.52[a] | 39.93±0.01[b] | 29.92±0.02[c] | 35.05±0.04[B] | 35.34±0.03[AB] | 35.57±0.07[A] | 33.37±0.18[C] |
| | C18:2 | 12.19±0.28[a] | 9.47±0.03[b] | 6.12±0.02[c] | 8.02±0.38[A] | 7.89±0.12[A] | 8.47±0.09[A] | 7.77±0.00[A] |
| | C20:0 | 0.40±0.31[a] | 0.50±0.01[a] | 0.79±0.36[a] | 0.92±0.38[A] | 1.09±0.11[A] | 0.79±0.09[A] | 0.46±0.01[A] |
| | C18:3 | 0.33±0.01[a] | 0.22±0.01[b] | 0.14±0.00[c] | 0.18±0.00[A] | 0.18±0.00[A] | 0.19±0.00[A] | 0.03±0.05[B] |
| | ∑SFA | 41.59±0.38[c] | 49.14±0.09[b] | 63.26±0.37[a] | 56.21±0.39[B] | 56.28±0.10[B] | 55.39±0.09[B] | 58.09±0.56[A] |
| | ∑MUFA | 45.42±0.92[a] | 40.09±0.01[b] | 30.03±0.02[c] | 35.18±0.04[B] | 35.48±0.03[AB] | 35.71±0.07[A] | 33.65±0.13[C] |
| | ∑PUFA | 12.57±0.21[a] | 9.70±0.03[b] | 6.26±0.02[c] | 8.20±0.38[AB] | 8.07±0.13[AB] | 8.66±0.10[A] | 7.80±0.05[B] |
| Iodine value | | 60.91±0.62[a] | 51.48±0.05[b] | 36.81±0.05[c] | 44.64±0.62[A] | 44.67±0.19[A] | 45.88±0.11[A] | 42.39±0.06[B] |
| Slip melting point (°C) | | 20.20±0.20[c] | 36.27±0.61[b] | 51.20±0.20[a] | 47.93±0.12[B] | 47.93±0.12[B] | 47.80±0.00[B] | 50.50±0.07[A] |

Values are presented as mean±SD, n = 3. Values with different lowercase superscript within the same row are significantly different ($p < 0.05$) between native fats. Values with different uppercase superscript within the same row are significantly different ($p < 0.05$) between shortenings. RPOL: red palm olein, PO: palm oil, PS: palm stearin, SFA: saturated fatty acid, MUFA: mono-unsaturated fatty acid, PUFA: poly-unsaturated fatty acid. SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

Table 2. Thermal profile of native fats, RPOL-based shortenings, and Commercial X

| Curve | | | Native fats | | | Shortening | | | Commercial X |
|---|---|---|---|---|---|---|---|---|---|
| | | | RPOL | PO | PS | SH-0 | SH-5 | SH-10 | |
| Crystallization | Transition Temperature (°C) | 1 | -4.47±0.24 | -5.30±0.12 | - | -5.15±0.06 | -5.40±0.01 | -5.42±0.01 | -5.27±0.06 |
| | | 2 | 2.13±0.00 | 4.40±0.18 | 6.89±2.45 | 5.25±0.06 | 4.74±0.01 | 4.84±0.06 | 5.05±0.18 |
| | | 3 | 29.74±0.11 | 29.87±0.06 | 34.19±3.22 | 26.11±0.12 | 24.63±0.01 | 24.99±0.06 | 27.06±0.13 |
| | $T_o$ (°C) | | 31.20±0.57[a] | 30.91±0.42[a] | 37.55±3.46[a] | 27.61±0.43[A] | 30.09±5.03[A] | 28.42±2.76[A] | 32.44±3.81[A] |
| | $T_f$ (°C) | | -28.80±0.00[b] | -6.87±0.47[a] | -7.71±4.11[a] | -7.38±0.45[B] | -6.34±1.36[B] | -8.44±0.03[B] | 7.82±0.18[A] |
| | Range (°C) | | 60.00±0.57[a] | 37.77±0.89[c] | 45.26±0.64[b] | 34.99±0.02[A] | 36.43±6.39[A] | 36.86±2.79[A] | 24.62±3.63[A] |
| Melting | Transition Temperature (°C) | 1 | -14.73±0.35 | -3.85±0.01 | -1.27±2.98 | -16.46±0.06 | -16.56±0.10 | -16.58±0.01 | - |
| | | 2 | -3.30±0.17 | 2.90±0.06 | 12.55±3.39 | -3.89±0.00 | -4.245±0.06 | -4.22±0.01 | -3.87±0.02 |
| | | 3 | 2.41±0.18 | 8.26±0.01 | 30.87±2.95 | 3.14±0.00 | 2.50±0.01 | 2.57±0.00 | 2.01±0.95 |
| | | 4 | 4.56±0.18 | 13.90±0.59 | 39.57±0.48 | 9.16±0.18 | 8.14±0.01 | 8.33±0.06 | 9.22±0.02 |
| | | 5 | 8.22±0.18 | 22.44±2.06 | 46.79±2.95 | 14.65±0.06 | 13.83±0.05 | 13.99±0.06 | 14.83±0.08 |
| | | 6 | 12.45±0.18 | 43.80±6.77 | 54.65±0.43 | 25.41±0.82 | 23.07±0.05 | 23.35±0.00 | 24.87±0.04 |
| | | 7 | - | - | 58.43±1.48 | 40.67±0.42 | 40.30±0.23 | 40.21±0.00 | - |
| | | 8 | - | - | - | 44.23±0.11 | 43.405±0.01 | 43.56±0.00 | 44.15±0.01 |
| | | 9 | - | - | - | 48.30±0.29 | 47.305±0.06 | 47.47±0.06 | 49.56±0.05 |
| | $T_o$ (°C) | | -19.20±0.00[b] | -6.08±1.80[a] | -7.68±0.68[a] | -20.93±0.36[B] | -20.46±0.53[B] | -20.65±0.56[B] | 6.28±0.91[A] |
| | $T_f$ (°C) | | 16.60±0.28[b] | 46.32±7.81[a] | 60.99±3.33[a] | 51.35±0.45[AB] | 50.23±0.28[B] | 50.83±0.30[B] | 52.31±0.00[A] |
| | Range (°C) | | 35.80±0.28[b] | 52.40±9.61[ab] | 68.67±2.45[a] | 72.28±0.81[A] | 70.68±0.81[A] | 71.48±0.86[A] | 46.03±0.91[B] |

Values are presented as mean±SD, n = 3. Values with different lowercase superscript within the same row are significantly different ($p < 0.05$) between native fats. Values with different uppercase superscript within the same row are significantly different ($p < 0.05$) between shortenings. RPOL: red palm olein, PO: palm oil, PS: palm stearin, $T_f$: offset temperature; $T_o$: onset temperature. SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

desirable physicochemical properties of a shortening. Upon blending, Table 2 shows that the number of melting peaks in RPOL-based shortenings increased as compared to those of native fats. This outcome was most likely due to the transition of polymorphic crystals which took place upon blending of the native fats; thus, further induced formation of more nucleation sites (Latip *et al.*, 2013).

Despite exhibiting different physicochemical properties, blends of RPOL with PO and PS at different ratios resulted in SH-0, SH-10, and SH-15 with not much difference in terms of FAC, IV, SMP (Table 1), and thermal profiles (Table 2). Similarities between these shortenings were also observable in their solid fat profiles (Figure 1). These findings indicated the insignificant effect of RPOL on the physical properties of the shortenings at 5% (SH-5) and 10% (SH-10) levels, despite its greater liquid-like properties. According to Latip *et al.* (2013) and Biswas *et al.* (2017), determination of SFC is critical at both 25°C and 37°C as they represent the room and body temperature, respectively. With reference to Figure 1, at 25°C, the SFC in SH-0 (35.79±0.18%) was significantly ($p < 0.05$) higher than that of SH-5 (34.71±0.01%) and SH-10 (33.58±0.11%) which highlighted the significant effect of increasing RPOL content from 0% to 10% towards the SFC profile of the shortenings. However, at 37°C, the SFC of the shortenings were insignificantly different ($p$

> 0.05) (10.25-10.84%) from each other. This outcome demonstrated the potential use of these shortenings in the development of non-waxy SCC upon consumption. Nevertheless, at both 25°C and 37°C, the SFC in Commercial X (25°C, 39.79%; 37°C, 16.32%) were significantly ($p < 0.05$) higher than that of RPOL-based shortenings (25°C, 33.58-35.79%; 37°C, 10.25-10.84%). Additionally, Figure 1 displays higher SFC in Commercial X than those of RPOL-based shortenings at most temperatures tested. This is contributed by the higher amount of C18:0 which resulted in lower IV and higher SMP, $T_f$ and $T_0$ as compared to the RPOL-based shortenings. To conclude, the Commercial X exhibited greater solid-like property than the developed RPOL-
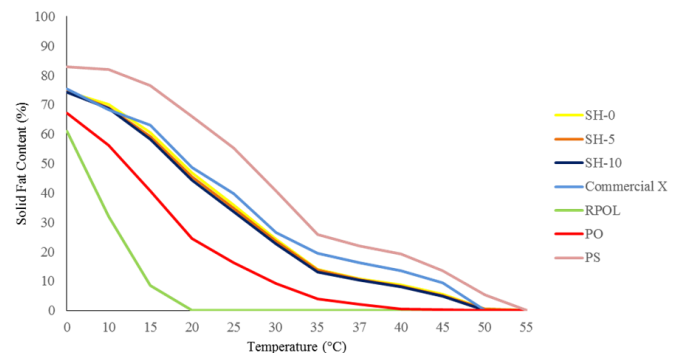


Figure 1. Solid fat content of native fats, RPOL-based shortenings, and Commercial X shortening. RPOL: red palm olein, PO: palm oil, PS: palm stearin. SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

based shortenings.

In a different study done by Mat Yusoff *et al.* (2013), SFC of five fat blends extracted from five commercial SCC samples was reported. With reference to this study, the SFC of the RPOL-based shortenings (25°C, 33.58-35.79%; 37°C, 10.25-10.84%) falls within the SFC of these five commercial fat blends (25°C, 16.7–35.3%; 37°C, 6.6–16.2%). The IV (44.64-45.88) and SMP (47.80-47.93°C) of these RPOL-based shortenings also fall within the ranges of IV (40.72-47.91) and SMP (42-48°C) of these five commercial fat blends (Mat Yusoff *et al.,* 2013). These discoveries suggested similarities between the RPOL-based shortenings with those of fat portions of the commercial SCC samples evaluated, despite being slightly different from the Commercial X as discussed earlier. Moreover, based on Figure 1, significant solid fat still presents in the RPOL-based shortenings at higher temperatures of up to 37°C (10.25-10.84%), 40°C (7.98-8.67%), and 45°C (4.95-5.54%). This finding signified the importance of blending the RPOL with PO (semi-solid fat) and PS (hard fat) in contributing the desirable SFC towards the developed shortenings. Blends of RPOL, PO, and PS also resulted in shortenings with improved plasticity as compared to those of individual fats which further contributed to SCC exhibiting desirable melting profile, texture, and creaming performance.

### 3.2 Antioxidant compounds and colour properties of red palm olein-based shortenings

Carotene, tocopherol, and tocotrienol are antioxidant compounds potentially used to retard free radical release due to oxidation reaction (Leonardis *et al.,* 2016). Table 3 clearly shows that the RPOL contains significantly ($p < 0.05$) high carotene content (628.12±5.08 ppm) as compared to both PO (2.61±1.75 ppm) and PS (5.53±2.24 ppm). The carotene content in RPOL was also higher than those reported in carrot (45.0 ppm), chillies (26.16 ppm), tomatoes (120-278 ppm), and banana (0.18-8.82 ppm) (Giuffrida *et al.*, 2014; Saini *et al.,* 2015). Incorporation of 5% and 10% RPOL to the fat blends increased the carotene content from 18.47 ppm to 50.32ppm and 84.75 ppm, respectively. Carotene is a red

-orange pigment naturally present in RPOL (Butt *et al.,* 2006). Therefore, an increase in the amount of RPOL i.e. the carotene content was reflected by a significant ($p < 0.05$) decrease in the $L^*$ value, significant ($p < 0.05$) decrease in both the $a^*$ and $b^*$ values (Figure 2(b)), and enhanced the yellowish colour of the shortenings (Figure 2(a)). This finding was in line with the study conducted by El-Hadad *et al.* (2011) which reported a lower $L^*$ value (31.65) in functional biscuits containing 60% RPOL as compared to the same biscuit formulation containing 40% RPOL (33.50). In another study done by Butt *et al*. (2004) and Kumar *et al*. (2016), the incorporation of 20% RPOL in shortenings meant for biscuits and chocolate spread, respectively, was accepted by the consumers in terms of colour. According to McAvoy (2014), red-orange colour imparted by RPOL due to the presence of carotene compounds was acceptable as natural food colourant based on Global Regulations of Food Colours.
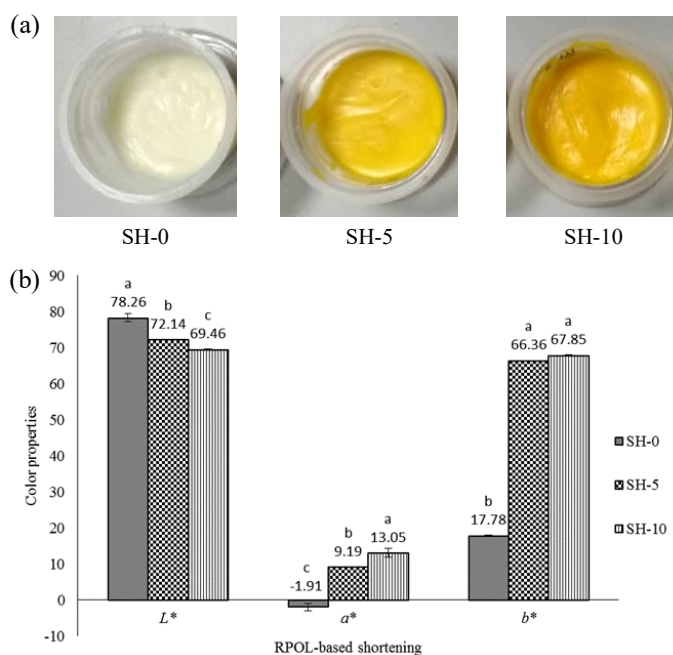
(a)



(b)



Figure 2. (a) Images of RPOL-based shortenings and (b) Colour properties of RPOL-based shortenings. Values are presented as means, n = 3. Bars with different notations are significantly different for each colour property ($p < 0.05$). RPOL: red palm olein, PO: palm oil, PS: palm stearin. SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

Table 2. Thermal profile of native fats, RPOL-based shortenings, and Commercial X

| Properties | Native fats | | | Shortening | | |
|---|---|---|---|---|---|---|
| | RPOL | PO | PS | SH-0 | SH-5 | SH-10 |
| Carotene contents (ppm) | 628.12±5.08[a] | 2.61±1.75[c] | 5.53±2.24[b] | 18.47±0.42[C] | 50.32±7.94[B] | 84.75±1.22[A] |
| Tocopherol contents (ppm) | 268.33±2.08[a] | 163.00±0.00[b] | 87.67±0.58[c] | 142.67±2.08[B] | 140.33±1.53[B] | 150.33±3.06[A] |
| Tocotrienol contents (ppm) | 820.33±1.39[a] | 543.33±1.30[b] | 288.33±0.39[c] | 425.00±4.36[A] | 431.00±1.00[A] | 399.67±54.50[A] |

Values are presented as mean±SD, n = 3. Values with different lowercase superscript within the same row are significantly different ($p < 0.05$) between native fats. Values with different uppercase superscript within the same row are significantly different ($p < 0.05$) between shortenings. RPOL: red palm olein, PO: palm oil, PS: palm stearin. SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

Besides carotene, Table 3 shows that the RPOL was significantly ($p < 0.05$) higher in total tocopherol and tocotrienol content (1088.66 ppm) as compared to PO (706.33 ppm) and PS (376.00 ppm). The value was higher than those of vegetable oils including sunflower (655.2 ppm), soybean (821.7 ppm), and olive (292.9 ppm) oils (Rafalowski *et al.,* 2008). Substituting 10% of RPOL significantly contribute to the high content of tocopherol in SH-10 (150.33±3.06 ppm) as compared to both SH-0 (142.67±2.08 ppm) and SH-5 (140.33±1.53 ppm). However, no significant differences ($p > 0.05$) in tocotrienol content was observed in all three blends (399.67-431.00 ppm). In general, as the RPOL content increased, the total carotene, tocopherol, and tocotrienol content in the shortenings increased. These outcomes demonstrated the potential of RPOL in enhancing the antioxidative properties of food products (Al-Saqer *et al.,* 2004; Butt *et al.,* 2006; Kumar *et al.,* 2016) and fulfilling consumers' demand for functional foods (Dauqan *et al.,* 2011; Manorama, 2014). A similar trend was also reported by El-Hadad *et al.* (2010, 2011) where incorporation of 20-60% RPOL resulted in functional biscuit and chocolate spread with enhanced carotene (140-188 ppm) and total tocopherol and tocotrienol (282-577 ppm) content.

*3.3 Physical properties and creaming performance of red palm olein-based shortenings*

In accord to Table 4, incorporation of RPOL decreased the hardness of the shortenings due to the liquid property of the RPOL. However, SH-5 showed the hardest texture (139.95 N±1.39) as compared to SH-0 (117.71 N±1.07) and SH-10 (84.58 N±4.20). This could probably be due to inconsistency in the homogenizing process which contributed to irregular crystal formation. These crystals increased the shortening's hardness and therefore caused the post-hardening phenomenon (Duns, 1985; Jeon, *et al.,* 2012).

In this study, PS played an important role as the hard stock which provided structural support to the product and assisted in maintaining the product's structure. It is high in tripalmitin (PPP) which tends to crystallize in β polymorphic form (Yu *et al.,* 2009). However, all shortenings developed in this study were composed of a similar amount of PS (50% w/w), thus differences in their texture and polymorphic forms were mainly contributed by the PO and RPOL content. Table 4 shows β' as the main polymorphic form in SH-0. This outcome was most likely due to the presence of 50% (w/w) PO which exhibited significantly ($p < 0.05$) higher palmitic acid (43.02±0.06%) than that of RPOL (35.70±0.55%) (Table 1). High palmitic acid content promotes β' polymorphic form, thus PO acts as a β' crystal promoter

and imparts smooth mouth-feel, firm texture, and glossy appearance towards the shortening (Aini and Miskandar, 2007; Pande *et al.,* 2012; Zaliha *et al.,* 2014). The transition of polymorphic forms took place from the β' in SH-0 to a mixture of β' and β in SH-5, dominated by the former. The further polymorphic transition occurred in SH-10 which also possessed a mixture of β' and β polymorphic forms, yet dominated by the latter. This observation indicated a decrease in β' polymorphic form as the amount of PO (i.e. palmitic acid content) decreased from SH-0 to SH-10. Simultaneously, the shortenings increased in β polymorphic form as the amount of RPOL increased. This finding was in line with Pande *et al*. (2012) which stated that most soft oils including canola, soybean, sunflower, and olive oils crystallize in β form, and this polymorphic form results in softer fats with grainy mouth-feel or texture. Despite the addition of 5% (w/w) RPOL, the SH-5 was still dominated by β' polymorphic form which contributed to its hardness. On the other hand, the addition of 10% (w/w) RPOL was adequate in producing a shortening with higher β polymorphic form and therefore decreased its hardness.

Table 4. Physical properties, and creaming performance of RPOL-based shortenings

| Properties | | Shortening | |
|---|---|---|---|
| | SH-0 | SH-5 | SH-10 |
| Hardness (N) | 117.71±1.07[b] | 139.95±1.39[a] | 84.58±4.20[c] |
| Polymorphism (Å) 4.6 | - | - | - |
| 4.5 | 4.58s | 4.59m | 4.59s |
| 4.4 | 4.45m | 4.46m | 4.45m |
| 4.3 | - | 4.34vw | 4.33vw |
| 4.2 | 4.22w | 4.25vw | 4.25vw |
| 4.1 | - | 4.15vw | 4.16vw |
| 4.0 | - | - | - |
| 3.8 | 3.89s | 3.89m | 3.89m |
| Polymorphic forms | β' | β'> β | β> β' |
| Creaming performance (cm³/g) 5 min | 2.11±0.11[b] | 2.28±0.12[ab] | 2.52±0.09[a] |
| 10 min | 2.47±0.12[a] | 2.42±0.06[a] | 2.48±0.03[a] |
| 15 min | 2.61±0.02[a] | 2.40±0.02[a] | 2.48±0.02[a] |
| 20 min | 2.41±0.04[a] | 2.50±0.08[a] | 2.43±0.04[a] |
| 25 min | 2.49±0.05[ab] | 2.37±0.04[b] | 2.33±0.05[b] |
| 30 min | 2.49±0.09[ab] | 2.35±0.05[bc] | 2.24±0.04[c] |
| 35 min | 2.27±0.08[b] | 2.32±0.01[b] | 2.20±0.03[b] |

Values are presented as mean±SD, n = 3. Values with different lowercase superscript within the same row are significantly different ($p < 0.05$). SH-0 (0:50:50), SH-5 (5:45:50), and SH-10 (10:40:50) are shortenings made of RPOL:PO:PS blends at different ratios.

Besides affecting the textural properties, the polymorphic form was also important in determining the creaming performance of a shortening. As stated by Buitimea-Cantúa *et al*. (2017), shortening with greater

β' polymorphic form was proved to exhibit excellent creaming performance. This is because β' polymorphic form was smaller, more uniform, and smoother than β polymorphic form and therefore was better in incorporating air during creaming (Nor Aini *et al.,* 1989). With reference to Table 4, within the first 15 mins of beating, both SH-0 and SH-5 increased in their specific volumes from 2.11 to 2.61 cm³/g and from 2.28 to 2.40 cm3/g, respectively. This outcome concluded their better creaming performance as compared to SH-10 which gradually decreased in its specific volume from 2.52 to 2.48 cm3/g within a similar beating time. As stated earlier, β' polymorphic form was better in creaming performance, thus the SH-10 which was dominated by β polymorphic form exhibited poorer creaming performance than those of SH-0 and SH-5 which were mainly composed of β' polymorphic form. Further beating for another 20 min resulted in a significant ($p < 0.05$) decrease in the creaming performance of SH-10. A similar trend was also observed in SH-0 and SH-5, yet the SH-0 showed better overall creaming performance than that of both SH-5 and SH-10. According to Osman and Nor Aini (1999), continuous beating resulted in greater heat release which melted the fat and sugar in the beaten sample; thus, increasing the sample's weight and further degrading its creaming performance. On the other hand, Porcello *et al.* (1987) stated that a shortening must have 45.0%, 25.0%, and 12.5% SFC at 25, 30, and 37 ˚C, respectively, in order to exhibit good plasticity for excellent creaming performance. Based on Figure 1, the SFC of all RPOL-based shortenings falls within these suggested values which indicated their potential to produce SCC with good creaming performance.

## 4. Conclusion

In overall, blends of 5-10% (w/w) RPOL with 45-50% (w/w) PO and 50% (w/w) PS resulted in shortenings (SH-5 and SH-10) which nearly resembled the Commercial X in terms of solid fat profiles. The RPOL also resulted in enhanced carotene (50.32-84.75 ppm) and tocopherol (140.33-150.33 ppm) content in the shortenings, besides desirable tocotrienol (399.67-431.00 ppm) content. More ß polymorphic form was produced as the RPOL level increased, and the SH-5 exhibited better creaming performance than that of SH-10 which is more desirable for an SCC product. This study proved the significant effect of RPOL in enhancing the natural antioxidant compounds in shortenings meant for SCC whilst exhibiting acceptable physicochemical properties. Future studies are highly recommended to incorporate RPOL in the varying type of food products and to determine the stability of these beneficial compounds upon storage.

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