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*Original Article*

# Properties of healthy oil formulated from red palm, rice bran and sesame oils

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## Abstract

A healthy edible oil was developed by blending red palm, rice bran and sesame oils at various proportions to achieve an oil blend with balanced ratio of fatty acids as recommended by the American Heart Association. The optimal blend was red palm oil 33.0: rice bran oil 35.0: sesame oil 32.0 (% by weight), which contained saturated, monounsaturated, and polyunsaturated fatty acids in the ratio 1.00: 1.33: 1.02. The optimal blend was rich in natural antioxidants, including gamma-oryzanol, tocopherols, sesamin, and carotenoids at 524, 454, 362 and 254 mg/kg, respectively. The panelists were satisfied with the sensory characteristics of the oil; the quality of the oil stored at 30 °C remained acceptable by the product standard for more than 120 days. This developed oil blend offers potential as a healthy edible oil that is balanced in fatty acids and high in powerful antioxidants.

**Keywords:** blending, healthy oil, red palm oil, rice bran oil, sesame oil

## 1. Introduction

According to the American Heart Association guidelines, healthy cooking oils should contain saturated, monounsaturated , and polyunsaturated fatty acids in the ratio 1.0: 1.3: 1.0 (Weisweiler, Janetschek, & Schwandt, 1985). Other desirable properties include stability after repeated used and functional values of bioactive compounds naturally present in the oils. Balancing the fatty acids ratio and enhancing the stability of the oil can be practically achieved by blending oils.

Blending oils not only provides a balance of the fatty acids, but also combines the potency of the selected oils. Red palm oil would be the best choice for developing an oil blend, considering its availability and overall health benefits. Red palm oil can be prepared from palm oil that is abundant in Thailand. It is suitable for high-temperature cooking and contains high quantities of carotenoids and vitamin E. However, red palm oil is not acceptable to consumers, because it contains a high amount of saturated fatty acids and clouds easily when chilled. To improve the stability and the balance of fatty acids, blending red palm oil with other oils that contain more polyunsaturated fatty acids could be an effective, simple and eco-friendly technique. Benefits of other blends have been reported previously (Choudhary, Grover, & Sangha, 2013).

This study explored blends of red palm oil with rice bran and sesame oils, as both rice bran and sesame oils are commercially available in Thailand, are high in PUFA, and contain unique bioactive compounds. Rice bran oil is high in gamma-oryzanol that is effective in decreasing cholesterol levels in blood, reducing cholesterol synthesis, and treating menopausal disorders (Gopal, Khatoon, & Babylatha, 2005). Sesame oil has a pleasant and unique taste with remarkable amounts of sesamin, sesamolin and sesamol that have been shown to have antioxidative, antihypertension, hypocholes-

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teremia, anticancer, and immunoregulation properties (Shahidi, Amarowicz, Abou-Gharbia, & Shehata, 1997). The physicochemical, stability and sensory properties of the oil blends were determined, as these properties might change in unpredictable ways. The data obtained is of fundamental importance to consumers and beneficial for promoting new products of this type.

## 2. Materials and Methods

### 2.1 Materials

Red palm oil with 3.72 mg $kg^{-1}$ phosphorus and 0.15% free fatty acid was prepared from crude palm oil by acid-water degumming. The rice bran oil, cold pressed sesame oil, potato sticks, and palm olein were purchased from the local supermarket. Fatty acid standards were purchased from Supelco Inc., PA, USA. Carotenoids, gamma-oryzanol, tocopherol and sesamin standards were purchased from Sigma-Aldrich Co., Ltd., Germany.

### 2.2 Blend preparation

The red palm, rice bran and sesame oils were blended in 10 different ratios (Table 1) formulated using Mixture Designs within the ranges 20-50% red palm oil, 30-60% rice bran oil, and 10-50% sesame oil. The oils were blended at 40°C with continuous stirring at 250 rpm for 2 minutes. The amounts of saturated, monounsaturated, and polyunsaturated fatty acids were calculated, and the ratio was optimized using Design-Expert software (Figure 1).

The optimized proportions of the oils were determined to achieve the desired physical, chemical, and nutritional properties. Regarding the nutritional properties, the fatty acid composition should comply with the American Heart Association Guideline. Non-linear programming was used to determine the optimum combination.

### 2.3 Physical analysis

The viscosity was measured with a Brookfield viscometer (Model LVDV-II+, USA) at the constant shear rate at 200 rpm, and at 25, 35 and 40°C. Color (L*, a*, b* color coordinates) was measured using a Minolta Colorimeter (model CR-400, Japan).

Table 1. The blend proportions tested.

| Formula | Component oil content (% by weight) | | |
|---|---|---|---|
| | Red palm oil | Rice bran oil | Sesame oil |
| 1 | 50.0 | 40.0 | 10.0 |
| 2 | 46.0 | 30.0 | 24.0 |
| 3 | 30.0 | 45.0 | 25.0 |
| 4 | 25.0 | 23.5 | 52.0 |
| 5 | 20.0 | 57.0 | 23.0 |
| 6 | 53.0 | 35.0 | 12.0 |
| 7 | 33.0 | 35.0 | 32.0 |
| 8 | 41.0 | 32.0 | 27.0 |
| 9 | 37.0 | 50.0 | 13.0 |
| 10 | 40.0 | 50.0 | 10.0 |

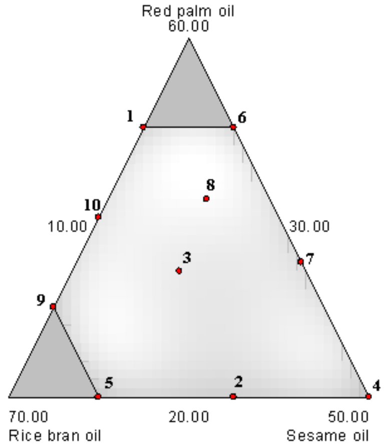


Figure 1. Augmented D-optimal mixture design proportions and reference numbers for 10 blend formulas.

### 2.4 Chemical analysis

The iodine, peroxide, and p-anisidine values were measured following the methods of American Oil Chemists' Society (American Oil Chemists' Society, 1997). Free fatty acid content measurement followed Peña, Anguiano, and Arredondo (1992). Total oxidation was estimated using the formula: Total oxidation = 2 x peroxide value + p-anisidine value (Shahidi & Wanasundara, 2002). Free DPPH radical scavenging activity was determined following Kim (2005). Undesirable substance determinations were according to Codex Alimentarius Standard 193-1995 and the European Commission (EC No. 1881/2006) (Lacoste & Raoux, 2003). The fatty acid composition was detected with a GC (Agilent Technologies) equipped with a hydrogen flame ionization detector (FID). The column used was a silica capillary column (HP-5MS 30 m × 0.25 mm ID × 0.25 µm film thickness). The fatty acid standards were tested under the same conditions to identify the peaks. The fatty acid contents were estimated as the ratio of partial area to total peak area (Association of Official Analytical Chemists [AOAC], 2000). HPLC was used to determine the amounts of carotenoids (Ribeiro, Chu, Ichikawa, & Nakajima, 2008), gamma-oryzanol (Azrina, Maznah, & Azizah, 2008), tocopherol (Chen & Bergman, 2005), and sesamin (Saleem, Madhusudhana, & Kaviman, 2013).

### 2.5 Heavy metal analysis

The heavy metal content was determined by Inductively Coupled Plasma (ICP) Emission Spectrometry (Lacoste & Raoux, 2003).

### 2.6 Thermal analysis

The melting and crystallization behaviors of heated (60°C) samples were determined using a Perkin-Elmer Diamond DSC (Shelton, CT, USA) with indium and zinc as calibration references, at a flow rate of 100 mL $min^{-1}$ and pressure of 9 psi (Abdulkarim, Long, Lai, Muhammad, & Ghazali, 2007).

## 2.7 Consumer acceptance test

### 2.7.1 Oil blends

The blends were prepared at room temperature and stored in glass bottles (Figure 2). They were presented to 70 panelists to evaluate appearance, clarity, color, odor, and overall acceptability using the 9-point hedonic scale (Resurreccion, 1998). The experimental design was a randomized complete block design. The panelists sniffed coffee between evaluations of samples to remove any previous aroma from their nasal cavity.

### 2.7.2 Deep-fried potato sticks

Potato sticks were prepared and deep-fried in select oil blends using the method described by Sanchez-Muniz *et al*. (1993). Palm olein was used as control oil. Sensory testing of the deep-fried potatoes used the 9-point hedonic scale for specific attributes, namely appearance, aroma, odor, crispness, mouth feel, after taste, and overall acceptability (N= 70) as described by Resurreccion (1998). The experimental design was randomized complete block design.

## 2.8 Quality analysis during storage

The oil samples were packaged in 15-oz amber glass bottles with tightly closed caps leaving 2-oz of headspace and sealed under nitrogen gas. The bottles were stored for 120 days at 30±2°C and were sampled every 15 days for physicochemical analysis.

## 2.9 Statistical Analysis

All determinations were conducted in triplicates. The data were analyzed using ANOVA in SPSS version 17.0 (SPSS Inc., Chicago, USA). Data are expressed as mean ± standard deviation. Comparisons of means between treatments were completed using Duncan's New Multiple Range Test. Significances are based on 5% threshold (Montgometry, 2001).


Figure 2. The appearances of original component oils: RPO= red palm oil, RBO=rice bran oil, SSO=sesame oil; and of 10 alternative blends tested

## 3. Results and Discussion

## 3.1 Appearance

The red palm oil was darker, with red and yellow tint, whereas the rice bran and sesame oils were lighter colored and more green (Figure 2). The red color of red palm oil is imparted by carotenoids in it. As the physical mixing did not cause any structural changes to the oils, the color of the blends changed significantly ($p \geq 0.05$) with the blend ratio.

## 3.2 Fatty acid composition

The red palm oil contained 42.02% palmitic acid and 39.06% oleic acid; the rice bran and sesame oils contained 40.58 and 35.41% oleic acid and 32.99 and 47.12% linoleic acid, respectively. The quantities of saturated, monounsaturated, and polyunsaturated fatty acids in an oil were calculated as sum totals of each type of fatty acids. Red palm oil contained the most saturated fatty acids and monounsaturated fatty acids, followed by rice bran oil and sesame oil; sesame oil contained the most polyunsaturated fatty acids, followed by rice bran oil and red palm oil (Table 2). Accordingly, the polyunsaturated fatty acids / saturated fatty acids ratio, which is known as the polyenes index, was the highest for sesame oil, followed by rice bran and red palm oils. The polyunsaturated fatty acids / saturated fatty acids ratio indicates the tendency for autoxidation (Mendez, Sanhueza, Speisky, & Valenzuela, 1996).

## 3.3 Consumer acceptance test

The blend by Formula 7 had the highest score in all sensory attributes, followed by Formulas 8, 4, and 3 (Table 3). These four blends also provided the ratios of saturated, monounsaturated, and polyunsaturated fatty acids that were the closest to the American Heart Association Guideline. Accordingly, these four blends were selected for consumer acceptance testing of the deep-fried potato sticks. Physicochemical and thermal properties of these four formulations were also determined.

Although sensory evaluation of potato sticks deep-fried in the oil samples is not directly related to sensory characteristics of the oils, the data helps assess the potential for use as a cooking oil. The appearances of the fried potatoes are shown in Figure 3. The panelists found all the deep-fried potato samples acceptable, with the ratings for all sensory characteristics ranging from like slightly to like moderately. Among the oil blends, Formula 7 gave the highest scores for appearance, aroma, flavor, crispness, after taste, and overall acceptability of the fried potato sticks. In overall acceptability, the potato sticks fried in the blend by Formula 7 also scored the closest to the control (Table 4).

## 3.4 Viscosity

Viscosity is an indicator of quality and stability of an oil. The viscosity also significantly affects ability to coat and be absorbed by fried products. When the quantity of red palm oil in the blend increased, the viscosity increased ($P \leq 0.05$), whereas the viscosity tended to decrease with temperature (Figure 4). The changes in viscosity relate to the amount of saturated palmitic acid (Fasina, Hallman, Craig-Schmidt, & Clements, 2006), of which red palm oil has a high content.

Table 2. Fatty acid compositions of component oils.

| Fatty acid compositions (%) | Red palm oil | Rice bran oil | Sesame oil |
|---|---|---|---|
| Saturated fatty acid (g/100g) | | | |
| Lauric acid (C12:0) | 0.64 | ND | ND |
| Myristic acid (C14:0) | 1.21 | 0.45 | ND |
| Palmitic acid (C16:0) | 42.02 | 20.74 | 10.15 |
| Stearic acid (C18:0) | 6.23 | 1.94 | 5.69 |
| Arachidic acid (C20:0) | 0.30 | 0.72 | 0.67 |
| Behenic acid (C22:0) | 0.05 | 0.23 | 0.16 |
| Lignoceric acid (C24:0) | 0.07 | 0.38 | 0.10 |
| Monounsaturated fatty acid (%) | | | |
| Palmitoleic acid (C16:1n7) | 0.18 | 0.22 | 0.13 |
| *Cis*-9-Oleic acid (C18:1n9c) | 39.06 | 40.58 | 35.41 |
| *Cis*-11-Eicosenoic acid (C20:1n11) | 0.13 | 0.44 | 0.15 |
| Polyunsaturated fatty acid (%) | | | |
| *Cis*-9,12-Linoleic acid (C18:2n6) | 9.51 | 32.99 | 47.12 |
| α- Linolenic acid (C18:3n3) | 0.33 | 1.24 | 0.37 |
| Total saturated fatty acid (g/100g) | 50.52 | 24.46 | 16.77 |
| Total monounsaturated fatty acid (g/100g) | 39.37 | 41.24 | 35.69 |
| Total Polyunsaturated fatty acid (g/100g) | 9.84 | 34.23 | 47.49 |

| Fatty acid (g/100g) | Blend | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| C12:0 | 0.32 | 0.29 | 0.19 | 0.16 | 0.13 | 0.34 | 0.21 | 0.26 | 0.24 | 0.26 |
| C14:0 | 0.79 | 0.69 | 0.57 | 0.41 | 0.50 | 0.80 | 0.56 | 0.64 | 0.67 | 0.71 |
| C16:0 | 28.95 | 26.68 | 22.55 | 20.02 | 21.95 | 29.29 | 23.48 | 26.44 | 26.21 | 27.09 |
| C18:0 | 4.46 | 4.81 | 4.16 | 4.97 | 3.66 | 4.66 | 4.56 | 4.71 | 4.01 | 4.03 |
| C20:0 | 0.51 | 0.51 | 0.58 | 0.59 | 0.62 | 0.49 | 0.57 | 0.53 | 0.56 | 0.55 |
| C22:0 | 0.13 | 0.13 | 0.16 | 0.15 | 0.18 | 0.13 | 0.15 | 0.14 | 0.15 | 0.15 |
| C24:0 | 0.20 | 0.17 | 0.22 | 0.16 | 0.25 | 0.18 | 0.19 | 0.18 | 0.23 | 0.23 |
| C16:1n7 | 0.19 | 0.18 | 0.19 | 0.16 | 0.19 | 0.19 | 0.18 | 0.18 | 0.19 | 0.20 |
| C18:1n9c | 40.58 | 39.81 | 39.58 | 38.28 | 39.58 | 40.52 | 39.29 | 37.58 | 40.29 | 40.48 |
| C20:1n11 | 0.35 | 0.23 | 0.28 | 0.22 | 0.31 | 0.25 | 0.25 | 0.24 | 0.29 | 0.29 |
| C18:2n6 | 22.66 | 25.72 | 30.66 | 34.21 | 31.66 | 22.34 | 29.79 | 28.32 | 26.23 | 25.08 |
| C18:3n3 | 0.74 | 0.65 | 0.78 | 0.59 | 0.88 | 0.70 | 0.69 | 0.67 | 0.82 | 0.83 |
| SFA | 33.28 | 28.43 | 26.46 | 27.29 | 35.89 | 29.72 | 32.9 | 32.07 | 33.02 | 33.28 |
| MUFA | 41.12 | 40.22 | 40.05 | 38.66 | 40.08 | 40.96 | 39.72 | 38.00 | 40.77 | 40.97 |
| PUFA | 23.40 | 26.37 | 31.44 | 34.80 | 32.54 | 23.04 | 30.48 | 28.99 | 27.05 | 25.91 |
| PUFA/ SFA | 0.66 | 0.79 | 1.11 | 1.32 | 1.19 | 0.64 | 1.03 | 0.88 | 0.84 | 0.78 |
| SFA: MUFA: PUFA | 1.5:1.8:1.0 | 1.3:1.5:1.0 | 1.0:1.4:1.1 | 1.0:1.5:1.3 | 1.0:1.5:1.2 | 1.6:1.8:1.0 | 1.0:1.3:1.0 | 1.1:1.3:1.0 | 1.2:1.5:1.0 | 1.3:1.6:1.0 |

Notes: ND = Not detected, C12:0 = Lauric acid, C14:0 = Myristic acid, C15:0 = Pentadecanoic acid, C16:0 = Palmitic acid, C17:0 = Heptadecanoic acid, C18:0 = Stearic acid, C20:0 = Arachidic acid, C22:0 = Behenic acid, C24:0 = Lignoceric acid, C16:1n7 = Palmitoleic acid, C18:1n9c = Cis-9-Oleic acid, C20:1n11 = Cis-11-Eicosenoic acid, C18:2n6 = *Cis*-9,12-Linoleic acid, C18:3n3 = alpha- Linolenic acid

Table 3. Sensory evaluation of the 10 blends tested.

| Sample | Appearance | Clarity | Color | Odor | Overall liking |
|---|---|---|---|---|---|
| Formula 1 | $6.44^{c}\pm1.07$ | $5.96^{d}\pm1.70$ | $5.74^{g}\pm1.62$ | $4.63^{d}\pm1.40$ | $5.33^{e}\pm1.19$ |
| Formula 2 | $6.10^{d}\pm1.33$ | $5.89^{d}\pm1.37$ | $6.09^{fg}\pm1.28$ | $4.59^{d}\pm0.95$ | $5.46^{de}\pm0.91$ |
| Formula 3 | $7.03^{b}\pm0.80$ | $7.11^{b}\pm0.89$ | $6.71^{cd}\pm0.94$ | $5.14^{c}\pm1.22$ | $6.70^{b}\pm0.75$ |
| Formula 4 | $7.53^{a}\pm0.94$ | $7.61^{a}\pm0.82$ | $7.09^{abc}\pm1.13$ | $6.14^{a}\pm1.01$ | $6.63^{b}\pm0.87$ |
| Formula 5 | $6.64^{c}\pm0.99$ | $6.70^{bc}\pm1.40$ | $6.53^{de}\pm1.13$ | $5.73^{b}\pm1.19$ | $6.21^{c}\pm0.76$ |
| Formula 6 | $6.70^{c}\pm1.10$ | $6.54^{c}\pm1.38$ | $6.29^{ef}\pm1.33$ | $5.33^{bc}\pm1.60$ | $5.76^{d}\pm1.28$ |
| Formula 7 | $7.51^{a}\pm0.88$ | $7.56^{a}\pm1.02$ | $7.43^{a}\pm1.00$ | $6.47^{a}\pm0.97$ | $7.53^{a}\pm0.89$ |
| Formula 8 | $7.19^{b}\pm0.62$ | $7.00^{b}\pm0.83$ | $7.16^{ab}\pm0.74$ | $5.69^{b}\pm0.91$ | $6.73^{b}\pm0.70$ |
| Formula 9 | $6.49^{c}\pm0.72$ | $6.51^{c}\pm0.83$ | $6.99^{bc}\pm0.83$ | $5.34^{bc}\pm1.10$ | $6.17^{c}\pm0.80$ |
| Formula 10 | $6.56^{c}\pm0.63$ | $6.80^{bc}\pm0.97$ | $6.89^{bcd}\pm0.71$ | $5.51^{bc}\pm0.93$ | $6.17^{c}\pm1.17$ |

Notes: Mean values within each column followed by different superscripts (a, b, c, etc.) are significantly different (P≤0.05).

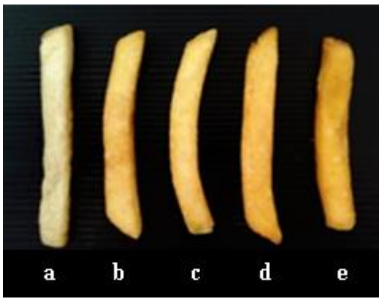


Figure 3. Appearances of potato sticks fried in different oil samples; (a) = fried in palm olein as control, (b) = fried in blend by Formula 3, (c) = fried in blend by Formula 4,(d); fried in blend by Formula 7, and (e) fried in blend by Formula 8.

Table 4. Sensory evaluation of potato sticks deep-fried in select oil blends.

| Sensory attribute | Control (palm olein) | Oil blend used | | | |
|---|---|---|---|---|---|
| | | Formula 3 | Formula 4 | Formula 7 | Formula 8 |
| Appearance | 7.07$^{a}$±1.13 | 6.55$^{b}$±0.83 | 7.20$^{a}$±1.11 | 7.30$^{a}$±0.73 | 7.15$^{a}$±0.81 |
| Aroma | 8.03$^{a}$±0.96 | 7.70$^{a}$±0.87 | 7.55$^{a}$±0.95 | 7.45$^{a}$±0.76 | 6.45$^{b}$±1.15 |
| Flavor | 7.00$^{a}$±1.12 | 6.30$^{a}$±1.13 | 6.95$^{a}$±1.50 | 6.80$^{a}$±1.06 | 5.15$^{b}$±1.72 |
| Crispness | 6.50$^{a}$±1.28 | 6.55$^{bc}$±0.89 | 6.00$^{c}$±1.59 | 7.55$^{a}$±1.10 | 7.05$^{ab}$±1.19 |
| Mouth feel | 7.00$^{a}$±1.63 | 7.15$^{a}$±0.81 | 6.90$^{a}$±1.59 | 6.20$^{b}$±1.06 | 4.40$^{c}$±1.31 |
| After taste | 8.10$^{a}$±1.74 | 7.15$^{a}$±0.67 | 7.00$^{a}$±0.97 | 7.20$^{a}$±0.83 | 4.65$^{b}$±1.69 |
| Overall liking | 8.00$^{a}$±1.38 | 7.45$^{b}$±0.64 | 7.45$^{b}$±0.89 | 7.76$^{a}$±0.97 | 6.04$^{c}$±1.70 |

Notes: Mean values within each column followed by different superscripts (a, b, c, etc.) are significantly different (P≤0.05).

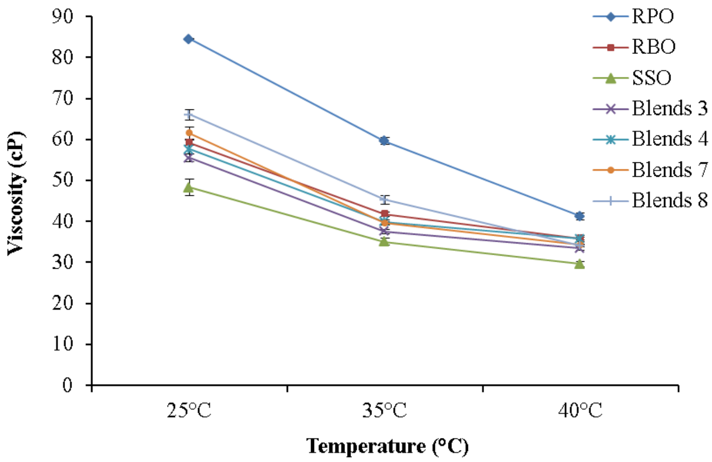


Figure 4. Viscosities of oil samples by temperature.

## 3.5 Chemical properties

Chemical properties of the oil samples are presented in Table 5. The free radical scavenging activity of the rice bran oil was considerably higher than those of the red palm and sesame oils, but the antioxidant activities of the blends did not differ significantly (P≥ 0.05). Antioxidants in oils are essential for stability, because they delay oxidation by free radicals. They also deliver various health benefits (Xiu-Qin, Chao, Yan-Yan, Min-Li, & Xiao-Gang, 2009).

The initial free fatty acid of the sesame oil was higher (P≤0.05) than those of the red palm and rice bran oils. Still, the free fatty acid contents of the four blends were mostly below the 0.6% maximum regulated by the Ministry of Public Health, the exception being Formula 4. The high free fatty acid of sesame oil is a consequence of cold extraction. This result suggests that it would be better to thermally process sesame oil to control its free fatty acids, although this might degrade its natural flavor. Greater health benefits of thermally processed sesame oil than of cold processed oil

Table 5. Chemical properties of oil samples.

| Sample | FRSA (%) | FFA (%) | IV (g $I_2$/100g) | PV (meq$O_2$/kg) | p-AV | TOTOX (2PV+p-AV) |
|---|---|---|---|---|---|---|
| RPO | $70.75^{b}\pm0.22$ | $0.15^{d}\pm0.03$ | $55.98^{g}\pm0.31$ | $2.12^{a}\pm0.76$ | $3.43^{d}\pm0.11$ | $7.67^{a}\pm0.14$ |
| RBO | $81.26^{a}\pm0.38$ | $0.21^{d}\pm0.03$ | $103.70^{b}\pm0.18$ | $0.11^{d}\pm0.72$ | $1.09^{e}\pm0.20$ | $1.31^{d}\pm0.11$ |
| SSO | $68.31^{c}\pm0.74$ | $1.22^{a}\pm0.07$ | $113.20^{a}\pm0.45$ | $2.28^{c}\pm0.89$ | $2.56^{a}\pm0.29$ | $7.12^{b}\pm0.23$ |
| Formula 3 | $71.75^{b}\pm1.18$ | $0.40^{c}\pm0.03$ | $96.83^{c}\pm0.76$ | $2.05^{b}\pm0.67$ | $3.14^{b}\pm0.45$ | $6.53^{c}\pm0.47$ |
| Formula 4 | $72.93^{b}\pm1.84$ | $0.71^{b}\pm0.03$ | $91.62^{d}\pm0.63$ | $2.11^{b}\pm0.48$ | $2.31^{d}\pm0.15$ | $7.24^{ab}\pm0.38$ |
| Formula 7 | $72.88^{b}\pm1.40$ | $0.41^{c}\pm0.03$ | $89.04^{e}\pm0.45$ | $2.08^{b}\pm0.54$ | $3.17^{c}\pm0.59$ | $7.33^{ab}\pm0.52$ |
| Formula 8 | $72.46^{b}\pm2.64$ | $0.39^{c}\pm0.01$ | $80.42^{f}\pm0.59$ | $2.18^{b}\pm0.43$ | $3.31^{c}\pm0.66$ | $7.67^{a}\pm0.29$ |

Notes: RPO= red palm oil, RBO= rice bran oil, SSO= sesame oil, FRSA= free radical scavenging activity, FFA= free fatty acids, IV= iodine value, PV= peroxide value, p-AV = p-anisidine value, standard of FFA = < 0.6%, standard of PV = <10 meqO2/Kg, standard of p-AV = <10, standard of TOTOX value = <10.

## 3.6 Thermal properties

The melting and crystallization behavior of an oil blend depended on the blend proportions of the three oils (Table 6). All the blends remained in liquid state at lower temperatures than the individual oils. Consumers prefer cooking oils that are generally clear or do not cloud easily when stored at low temperatures for prolonged periods. This finding confirms that balancing the fatty acid composition improved the stability of oil. Among the blends, Formula 7 was the most stable, and did not crystallize or cloud easily when stored at low temperatures for prolonged periods.

The blend by Formula 7, with red palm, rice bran and sesame oils in the ratio 33.0: 35.0: 32.0 (% by weight), was the best formula based on the overall essential properties, so it was selected for the next studies.

## 3.7 Antioxidant activity, bioactive compounds, and heavy metals in Formula 7 oil blend

The antioxidant activity of the blend by Formula 7 was 72.88%. The oil had 1,596.18 mg/kg of total antioxidants, including gamma-oryzanol, tocopherols, sesamin and carotenoids at 524.47, 454.38, 362.53 and 254.80 mg/kg, respectively. This blend would be an excellent source of natural antioxidants, which have been reported to protect against various illnesses (Miraliakbari & Shahidi, 2008).

The heavy metals in these vegetable oils might come from industrial wastes, vehicle exhaust, and chemical treatments. The ICP results indicate that the three original oils were prepared properly, and the blend was free of arsenic, lead, cadmium and mercury.

## 3.8 Storage stability of blend by Formula 7

Free fatty acids content and peroxide value could be used to assess the stability of an oil blend. Free fatty acids and peroxide value gradually increased with storage time, but the increase accentuated over time (Figure 5A, 5B). The rate of increase is positively correlated to the decrease in free DPPH radical scavenging activity (Figure 5C), as the peroxide formed by oxidation reacts with the antioxidants and consumes them (Leung, Koo, & Gua, 2006). So, the DPPH scavenging activity of the oil decreased continuously as peroxide value increased. In addition, the viscosity (Figure 5D) and color attributes, L* a* b* (Figure 5E) of the oil slightly decreased ($p>0.05$) during extended storage. Overall the results indicate that the oil quality did not change significantly during 120 days of storage in a dark bottle at 30°C. All quality measures were still within product standards (Codex Alimentarius International Food Standards, 1999). On comparing to a prior report on the stability of edible oils under storage conditions (Leung *et al*., 2006), it could be concluded that several antioxidants present in the oil blend effectively protected it against oxidative degradation.

Table 6. Thermal properties of oil samples.

| Sample | Heating | | | Cooling | | |
|---|---|---|---|---|---|---|
| | Onset temperature (°C) | Peak temperature (°C) | End temperature (°C) | Onset temperature (°C) | Peak temperature (°C) | End temperature (°C) |
| RPO | $6.14^{a}\pm0.93$ | $9.36^{a}\pm0.54$ | $13.15^{a}\pm0.59$ | $15.70^{a}\pm0.08$ | $13.40^{a}\pm0.59$ | $10.37^{a}\pm1.11$ |
| RBO | $-20.38^{e}\pm0.50$ | $-8.35^{e}\pm0.61$ | $-2.29^{e}\pm0.14$ | $-7.19^{f}\pm0.08$ | $-8.67^{e}\pm0.01$ | $-20.81^{d}\pm0.94$ |
| SSO | $-13.67^{d}\pm0.88$ | $-6.68^{d}\pm0.62$ | $1.12^{d}\pm0.35$ | $-5.28^{e}\pm0.71$ | $-7.06^{d}\pm1.05$ | $-12.04^{c}\pm2.81$ |
| Formula 3 | $-10.70^{c}\pm0.78$ | $-1.80^{b}\pm0.36$ | $2.26^{c}\pm0.16$ | $-2.10^{d}\pm0.03$ | $-6.71^{d}\pm0.66$ | $-21.42^{de}\pm1.68$ |
| Formula 4 | $-11.20^{c}\pm0.11$ | $-2.58^{bc}\pm0.09$ | $2.46^{c}\pm0.24$ | $-2.06^{d}\pm0.03$ | $-6.28^{d}\pm0.01$ | $-23.39^{e}\pm0.93$ |
| Formula 7 | $-10.46^{c}\pm0.21$ | $-2.48^{bc}\pm0.08$ | $2.70^{c}\pm0.09$ | $-0.58^{c}\pm0.21$ | $-5.12^{c}\pm0.23$ | $-23.77^{e}\pm0.83$ |
| Formula 8 | $-0.18^{b}\pm0.19$ | $3.54^{c}\pm0.24$ | $6.49^{b}\pm0.46$ | $4.76^{b}\pm0.06$ | $3.37^{b}\pm0.11$ | $-5.02^{b}\pm1.51$ |

Notes: RPO= red palm oil, RBO= rice bran oil, SSO= sesame oil.

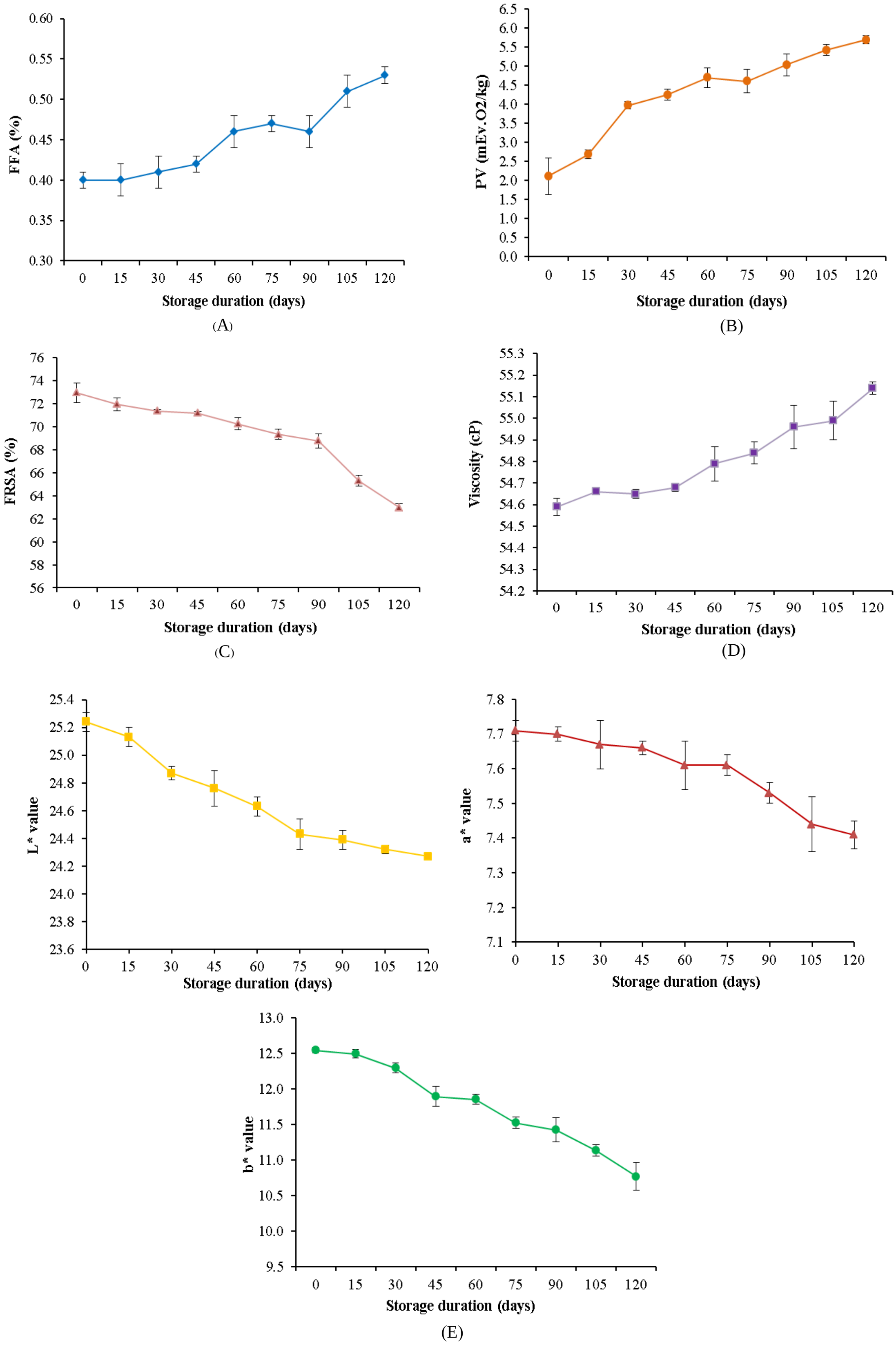


Figure 5. Time traces of free fatty acid (FFA) (A), peroxide value (PV) (B), DPPH radical scavenging activity (FRSA) (C), viscosity (D), and color attributes (E) of the oil blend by Formula 7 during storage

## 4. Conclusions

This study has shown that blending red palm oil with rice bran and sesame oils in the ratio 33.0: 35.0: 32.0 (% by weight) resulted in a ratio of saturated, monounsaturated , and polyunsaturated fatty acids close to that in the American Heart Association Guideline (1.00: 1.33: 1.02). The oil blend was an excellent source of natural antioxidants, of which gamma-oryzanol was the most predominant, followed by tocopherols, sesamin, and carotenoids. Panelists were satisfied with the sensory characteristics of the oil blend, and it remained within quality standards when stored at 30°C for more than 120 days. Our data provide nutritional facts and essential properties of this healthy edible oil blend.

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