Deep fat frying is a cooking method widely used in restaurants and industry. In simple terms, foods are immersed in a large quantity of oil heated to a high temperature, approximately 150–190°C. The simultaneous heat and mass transfer that occurs during the frying process contributes to the desirable flavor, texture, and appearance of fried foods. Frying oils, such as palm oil, soybean oil, and corn oil are commonly used as heating mediums. During the frying process, the oil is subjected to harsh conditions of high temperature in the presence of air and moisture which are associated with deteriorative chemical reactions, including oxidation, hydrolysis, and polymerization. Long-term deep frying can result in the formation of potentially toxic volatile and non-volatile compounds, including cyclic fatty acid monomers, heterocyclic amine, acrylamide, and trans fatty acids (1-3). It is therefore important to improve frying oil stability. Factors that affect the physicochemical properties and oxidative stability of oil during frying include the composition of the frying oil. Frying oil composition, for instance the fatty acid profile and the amount of antioxidants present in the oil, is of great importance since these affect the physicochemical properties and oxidative stability of the oil during frying. In general, vegetable oils with high amounts of saturated fatty acids are more stable toward thermal oxidation, making them suited to frying. However, with regard to nutritional aspect, oils containing high proportions of saturated fatty acids are considered harmful since it is linked to diseases such as hypertension, diabetes mellitus, hyperlipidemia, and atherosclerosis (4-6). To avoid compromising safety and stability, it is subsequently necessary to select a frying oil with an optimum ratio of saturated fatty acids and unsaturated fatty acids. Yet there is no single oil that contains a balanced fatty acid composition and antioxidants. Oil blending is a method that may improve the stability and nutritional profile of frying oil. It is a cheap and non-destructive method in which selected oils are blended to produce desirable frying oil. Several studies have investigated blending different oil types. Susheelamma and coworkers (7) reported that blends of groundnut, soybean, and sesame oils showed better oxidative stability based on the lower conjugated diene formation and peroxide value compared to the oils individually. They concluded that the high amount of natural antioxidants in sesame oil imparted a high resistance to thermal oxidation. Meanwhile, Mohamed et al. (8) formulated oil blends (10% and 20%, w/w) of black cumin oil and coriander oil with corn oil to enhance the thermal stability and functionality of high linoleic corn oil. By increasing the proportion of black cumin and coriander oils in the corn oil, polyunsaturated fatty acid levels decreased, while monounsaturated fatty acids content

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increased. Changes in fatty acids and tocopherols’ profile, and minor bioactive lipids found in coriander and black cumin oils resulted in better oxidative stability in oil blends compared to corn oil. Mishra and Sharma (9) revealed that blends of rice bran oil with sunflower oil showed better stability during repeated deep fat frying in terms of lower physicochemical parameters, including peroxide value, free fatty acid, iodine value, p-anisidine value, and color compared to pure rice bran oil (9). Srivastava and Singh (10) suggested that blending rice bran oil with mustard and palm oil improved the frying stability, oxidative stability index, and nutrition value of the oils. Arslan et al. (11) studied the effects of frying conditions on the physicochemical properties of palm olein-cottonseed oil blends (1 : 0, 3 : 2, 1 : 1, 2 : 3, and 0 : 1, w/w). The results show that the oxidative and frying performance of pure palm olein oil and cottonseed oil significantly improved through blending. They concluded that blending cottonseed oil with palm olein oil provided the oil blends (50% cottonseed oil: 50% palm olein oil and 40% cottonseed oil: 60% palm olein oil, w/w) with more desirable properties for human nutrition. In this study, palm oil was used as the main frying medium due to its high saturated fatty acid content.

In the present study, coconut oil and rice bran oil were selected based on the healthy saturated medium chain fatty acids in coconut oil and the presence of γ-oryzanol which is an antioxidant uniquely found in rice bran oil. Rice bran oil (RBO), coconut oil (CO), and palm oil (PO) were blended at ratios of 20 : 20 : 60, 25 : 25 : 50, 30 : 30 : 40, and 35 : 35 : 30 (v/v/v), respectively. The fatty acid profiles and nutritional content, including α-tocopherol and γ-oryzanol were determined. The physicochemical properties (color, viscosity) and the degradation parameters (total polar compounds, free fatty acid, peroxide value, and thiobarbituric acid reactive substances) were monitored during the deep frying of French-fries. Additionally, the sensory characteristics of the fries prepared in these oil blends were evaluated using 9-point hedonic scale.

MATERIALS AND METHODS

Chemicals and materials. Rice bran oil, coconut oil, and palm oil were purchased from a local grocery store in Thailand. Ethanol, methanol, acetonitrile, acetone, heptane, hydrochloric acid, tert-butyl methyl ether, tetrahydrofuran, and trichloroacetic acid were purchased from Merck company. Thiobarbituric acid and malonaldehyde bis (dimethylacetal) was purchased from Sigma-Aldrich. All the chemicals were analytical grade. Double-distilled and deionized water was used to prepare all the solutions.

Preparation of blended oils. Blends of rice bran oil (RBO), coconut oil (CO), and palm oil (PO) were prepared at ratios of 20 : 20 : 60, 25 : 25 : 50, 30 : 30 : 40, and 35 : 35 : 30 (v/v/v), respectively. Each oil blend was placed in a beaker and mixed by using a mechanical stirrer at 180 rpm for 15 min at room temperature.

Frying procedure. An electric 3.5-L stainless steel fryer (Fritel, Belgium) was used for frying. Each batch of frozen French fries (100 g) was fried in 3 L of oil blend or pure oil for 4 min at an initial temperature of 180°C. The total heating time was 8 h, including 10 min intervals between frying. There was no replenishment of the oil. After every eight cycle of the frying operation, 50 mL of oil was collected and stored at −20°C for further analyses. Pure palm oil was used as a conventional frying oil (Control).

Fatty acid composition analysis. The fatty acid profiles of the oils were analyzed using the gas chromatography technique, according to the in-house method based on the Compendium of methods for food analysis, Thailand (2003). The analyses were conducted in triplicate.

Determination of α-tocopherol. The α-tocopherol content of the oils was determined using high performance liquid chromatography (Agilent 1100 series). Briefly, 1 g of oil and 1 g ascorbic acid were dissolved in distilled water. Then, potassium hydroxide and ethanol were added. The mixture was mixed and heated at 85°C for 30 min and left to cool down. Tocopherol was extracted from the solution using hexane: ethyl acetate (8 : 2). The upper layer was collected and washed with distilled water, then evaporated until dried. The dried sample was then re-dissolved in ethanol and injected into HPLC with injection volume of 20 μL. The mobile phase was 100% methanol with flow rate of 1 mL/min. The tocopherol was separated on platinum (C18), 5 μ, 250×4.6 mm column and detected by Diode Array Detector (λ, 290 nm) detector.

Determination of γ-oryzanol. The γ-oryzanol was determined using the CODEX STAN 210-1999 method (12). The sample (0.02 g) was dissolved in 25 mL hexane and measured the absorbance at 315 nm using a UV-VIS spectrophotometer (Shimadzu UV-2550, Japan). The amount of γ- oryzanol was calculated according to the following equation:

\[
γ-oryzanol \text{ content (mg/g)} = \frac{(A - A_0) \times V \times W}{100} \times E
\]

where A is the absorbance, W is the sample weight (g), and E is the extinction coefficient of oryzanol (359 m<sup>−1</sup> cm<sup>−1</sup>).

Determination of free fatty acids. The free fatty acid content of the oils was determined according to the method of Rukunudin, White, Bern, and Bailey (13). Briefly, 2 g of oils were precisely weighed and dissolved in 5 mL of 95% ethanol. The mixture was titrated against 0.01 N sodium hydroxide using phenolphthalein as the indicator. The free fatty acid concentration in the oil was calculated using the following equation and reported as a percentage of the oleic acid:

\[
\text{Free fatty acid (mg/g)} = \frac{2.82 \times V \times 100}{W}
\]

where V is the volume of titrant and W is the sample weight (g).

Total polar compounds measurement. Total polar compounds were measured during frying using the Testo 270 (Testo Inc., Germany). Within the operating temperature of 160–200°C, the sensor of the Testo 270 was submerged into the oil sample and the oil was stirred gently for 20 s to allow even distribution. This rapid method detected the dielectric constant of the oil. This constant was converted to the content of total
polar compounds (%) based on the formula set up by the manufacturer.

**Determination of peroxide value.** The peroxide contents of oils were analyzed according to the AOCS method (14). Five grams of the samples were dissolved in 30 mL of a mixture solution of acetic acid: chloroform (3 : 2, v/v). Then, 0.5 mL of saturated potassium iodide solution was added. The solution was kept in the dark for 1 min prior to the addition of 30 mL of distilled water. The liberated iodine was titrated with 0.1 N sodium thiosulfate using starch solution as an indicator. The peroxide value was calculated using the following equation:

\[ \text{Peroxide value} = (S - B) \times N \times \text{thiosulfate} \times 1.000 \text{/ weight of sample in gram} \]

where \( S \) is the titration of the sample (mL), \( B \) is the titration of blank, and \( N \) is the normality of sodium thiosulfate. The peroxide value was expressed as milli-equivalent of active oxygen per kilogram of oil (meq O\(_2\)/kg oil).

**Determination of thiobarbituric acid reactive substances.** Thiobarbituric acid reactive substances (TBARs) was analyzed using the method of Mäisushisakul et al. (15) with some modifications. Briefly, 1 mL of oil sample was added into a screw cap test tube, followed by 10 mL of TBA reagent and the mixture was vigorously agitated for 1 min with a vortex mixer. The test tubes were placed in a boiling water bath for 40 min, and the sample was then cooled to room temperature. The samples were centrifuged at 5,000 g for 15 min and the top layer of liquid was carefully removed. The absorbance of the remaining aqueous layer was measured at 532 nm against a blank that contained TBA reagent without oil. Concentrations of TBARs was determined from a standard curve of malonaldehyde bis (dimethylacetal) (\( r^2 = 0.996 \)) and was expressed in \( \mu \)g MDA/mL of oil.

**Physical properties measurement.** The color of the fresh and used frying oil was measured in CIE \( L^*, a^*, b^* \) using colorimeter (Hunter lab, Color flex, USA). Oil viscosity was determined using Brookfield (Brookfield Programmable DV-II+, USA). All measurements were conducted at a sample temperature of 25°C.

**Sensory evaluation.** The French fries prepared in the different oils were assessed for the degree of desirable color, odor, taste, texture, and overall desirability by a panel of 50 untrained participants who declared themselves to be regular consumers of French fries. The samples were rated on the basis of a 9-point hedonic scale anchored by: 1 = 'Dislike extremely'; 2 = 'Dislike very much'; 3 = 'Dislike moderately'; 4 = 'Dislike slightly'; 5 = 'Neither like nor dislike'; 6 = 'Like slightly'; 7 = 'Like moderately'; 8 = 'Like very much'; and 9 = 'Like extremely' (16). Testing was carried out in a sensory laboratory under conditions of standard light and temperature (25°C). Each panelist was placed in an individual booth and was given 5 samples of 5–10 fries that were labeled via random numbering. The samples were fresh from the fryer and served without salt in a random order following a completely randomized design. Water and cream cracker biscuits were available as neutralizers between samples to avoid carryover effects.

**Statistical analysis.** All the data shown represents the mean values± standard deviation of triplicate measurements. The data results were analyzed by analysis of variance (ANOVA) using IBM SPSS STATISTICS 21.0. The differences between the mean values were compared using Duncan’s multiple-range test with a level of significance of \( p \leq 0.05 \).

**RESULTS**

**Fatty acid composition of the oils**

By analyzing the composition of fatty acids in various oil formulations before frying, it was found that each oil had different fatty acid composition. As shown in Table 1, pure rice bran oil contained the highest mono- and polyunsaturated fatty acids (72.4%) and the lowest saturated fatty acids (23.19%) compared to the other oils used in this study. The results show that pure coconut oil had the highest content of saturated fatty acids, which was up to 82.24% and consisted of 45.7% medium chain fatty acids (8–12 carbon atoms) and 13.34% unsaturated fatty acids. Pure palm oil contained saturated fatty acids and polyunsaturated fatty acids in similar proportions. The fatty acid composition of the oil blends varied depending on the mixing ratio. The oil blend of rice bran oil: coconut oil: palm oil at ratios of 20 : 20 : 60, 25 : 25 : 50, 30 : 30 : 40 and 35 : 35 : 30 showed increased saturated fatty acid content and decreased unsaturated fatty acid content, respectively.

**\( \alpha \)-Tocopherol and \( \gamma \)-oryzanol content**

The \( \alpha \)-Tocopherol content in blended oil was found to be different, as shown in Table 2. Pure palm oil had the highest \( \alpha \)-tocopherol content of 10.79 mg/100 g. For the blended oils, the amounts of \( \alpha \)-tocopherol were higher than for rice bran oil and coconut oil, but significantly lower than palm oil (\( p \leq 0.05 \)). The \( \alpha \)-tocopherol contents of the blended oils were in the range of 5.04–7.81 mg/100 g.

As shown in Table 2, \( \gamma \)-oryzanol was uniquely found in rice bran oil, with a content of 0.40%. For all blended oils, the \( \gamma \)-Oryzanol content was not significantly different (\( p > 0.05 \)). However, it tended to increase in proportion with the amount of rice bran oil with the \( \gamma \)-oryzanol content of 0.08, 0.10, 0.12, and 0.13, respectively.

**Free fatty acids content**

Table 3 shows the FFA content in different oils before and after frying. Pure palm oil, rice bran oil, and coconut oil contained 0.46, 0.34, and 0.23 mg KOH/1 g oil, respectively. For the oils blended in ratios of 20 : 20 : 60, 25 : 25 : 50, 30 : 30 : 40, and 35 : 35 : 30, the content of free fatty acids were in the range of 0.39–0.41 mg KOH/1 g oil.

Considering the influence of heating time, it was found that all the oil types had an increased FFA value with more frying cycles. At the end of the 8 h frying process, palm oil had the highest FFA content of 1.63 mg KOH/1 g oil, while all the oil blends had significantly lower FFA content compared with those of pure oils (\( p \leq 0.05 \)). The oil blended at ratios of 20 : 20 : 60 and 25 : 25 : 50 had the lowest FFA con-
Table 1. The fatty acid composition (%) of the frying oils.

| Oil Formulations | Fatty Acid | RBO | CO | PO  |
|------------------|------------|-----|-----|-----|
| 20 : 20 : 60     | Caprylic acid (C8 : 0) | 6  | 6  | 6  |
|                  | Capric acid (C10 : 0)  | 6  | 6  | 6  |
|                  | Lauric acid (C12 : 0)  | 6  | 6  | 6  |
|                  | Myristic acid (C14 : 0)| 6  | 6  | 6  |
|                  | Palmitic acid (C16 : 0)| 6  | 6  | 6  |
|                  | Stearic acid (C18 : 0)| 6  | 6  | 6  |
| 25 : 25 : 50     | Arachidic acid (C20 : 0)| 6  | 6  | 6  |
| 30 : 30 : 40     | Behenic acid (C22 : 0) | —  | —  | —  |

Different letters in the same row indicate significant difference at p≤0.05.

Table 2. The α-tocopherol content (mg/100 g) and γ-oryzanol content (%) of the oils before the frying procedure.

| Oil Formulations | α-Tocopherol content (mg/100 g) | γ-Oryzanol content (%) |
|------------------|---------------------------------|------------------------|
| PO               | 10.79±0.59^a                   | —                      |
| RBO              | 4.05±0.23^c                   | 0.40±0.05^a            |
| CO               | 0.40±0.01^f                   | —                      |
| 20 : 20 : 60     | 5.04±0.06^d                   | 0.08±0.01^b            |
| 25 : 25 : 50     | 5.91±0.07^c                   | 0.10±0.00^b            |
| 30 : 30 : 40     | 7.71±0.16^b                   | 0.12±0.01^b            |
| 35 : 35 : 30     | 7.81±0.34^b                   | 0.13±0.01^b            |

Different letters in the same column indicate significant difference at p≤0.05.

Table 3. The Free Fatty Acid Content (mg KOH/g oil) of oils, before and after 8 h of frying.

| Oil Formulations | Free Fatty Acid Content (mg KOH/g oil) |
|------------------|---------------------------------------|
| Before           | After                                 |
| PO               | 0.46±0.03^a                          | 1.63±0.04^a             |
| RBO              | 0.34±0.06^c                          | 1.09±0.04^b             |
| CO               | 0.23±0.02^d                          | 1.10±0.05^b             |
| 20 : 20 : 60     | 0.41±0.03^b                          | 0.75±0.03^d             |
| 25 : 25 : 50     | 0.39±0.03^b                          | 0.76±0.04^d             |
| 30 : 30 : 40     | 0.40±0.02^b                          | 0.88±0.03^c             |
| 35 : 35 : 30     | 0.39±0.05^b                          | 0.90±0.03^c             |

Different letters in the same column indicate significant difference at p≤0.05.

The changes in the Peroxide value (PV) of oil blends during frying are given in Table 5. Palm oil and rice bran oil contained the lowest PV (4.46 and 4.48 meq O₂/kg, respectively), while coconut oil possessed the highest PV (9.16 meq O₂/kg) compared to the other
fresh oils. Considering the PVs of the oil samples at the sixteenth frying, the oils blended at ratios of 20:20:40, 25:25:50, and 30:30:40 had the lowest PV of 75.96, 82.22, and 83.91 meq O₂/kg, respectively.

**Thiobarbituric acid reactive substances**

Thiobarbituric acid reactive substances (TBARs) analysis is one of the most widely used assays to evaluate the progress of lipid oxidation. Changes in the oils’ TBARs are shown in Table 6. Fresh coconut oil had the highest TBARs of 2.37 μg MDA/mL compared to the other fresh oils. At the sixteenth frying, palm oil and coconut oil had the lowest TBARs of 3.48 and 4.36 μg MDA/mL, respectively. However, considering among the oil blends, the 25:25:50 and 30:30:40 oil blends had the lowest TBARs of 7.06 and 8.49 μg MDA/mL, respectively.

**Oil viscosity**

The viscosity of each oil formula was measured, then the percentage changes in the oil viscosity were calculated before and after frying, as shown in Table 7. The viscosity of each oil was found to increase after frying French fries at 180°C for 8 h. Palm oil had the least vis-

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**Table 4.** Total polar compound content (%) of oil during frying at 0, 8, 16, 24, and 32 cycles.

| Oil Formulations | 0<sup>ab</sup> | 8<sup>ab</sup> | 16<sup>ab</sup> | 24 | 32 |
|------------------|---------------|---------------|---------------|---|---|
| PO               | 9.1 ± 0.2     | 10.7 ± 0.3    | 12.7 ± 1.0    | 14.2 ± 1.9<sup>b</sup> | 16.5 ± 1.0<sup>b</sup> |
| RBO              | 10.7 ± 2.4    | 12.8 ± 2.5    | 14.8 ± 1.6    | 17.2 ± 1.9<sup>a</sup> | 19.0 ± 1.3<sup>a</sup> |
| CO               | 11.2 ± 2.5    | 13.2 ± 2.0    | 15.2 ± 2.9    | 17.0 ± 2.0<sup>a</sup> | 19.2 ± 0.3<sup>a</sup> |
| 20:20:60         | 9.1 ± 1.1     | 11.7 ± 0.8    | 14.0 ± 0.8    | 16.4 ± 1.2<sup>b</sup> | 19.1 ± 1.4<sup>a</sup> |
| 25:25:50         | 9.4 ± 1.1     | 11.3 ± 0.7    | 13.7 ± 0.7    | 15.1 ± 0.7<sup>ab</sup> | 17.4 ± 0.7<sup>b</sup> |
| 30:30:40         | 9.3 ± 1.4     | 11.4 ± 0.6    | 13.6 ± 0.7    | 15.3 ± 0.8<sup>b</sup> | 17.3 ± 0.3<sup>b</sup> |
| 35:35:30         | 9.1 ± 1.0     | 11.8 ± 0.8    | 13.5 ± 0.3    | 14.9 ± 0.9<sup>ab</sup> | 17.1 ± 0.5<sup>b</sup> |

Different letters in the same column indicate significant difference at p≤0.05.

**Table 5.** Peroxide value (meq O₂/kg) of oil during frying at 0, 8, 16, 24, and 32 cycles.

| Oil Formulations | Frying cycles |
|------------------|---------------|
|                  | 0  | 8  | 16 | 24 | 32 |
| PO               | 4.46 ± 0.96<sup>d</sup> | 62.40 ± 3.56<sup>b</sup> | 90.50 ± 4.99<sup>b</sup> | 19.16 ± 2.27<sup>abc</sup> | 9.88 ± 2.77<sup>c</sup> |
| RBO              | 4.48 ± 0.99<sup>d</sup> | 62.40 ± 3.56<sup>b</sup> | 90.50 ± 4.99<sup>b</sup> | 19.16 ± 2.27<sup>abc</sup> | 9.88 ± 2.77<sup>c</sup> |
| CO               | 9.16 ± 1.08<sup>a</sup> | 76.06 ± 7.36<sup>a</sup> | 109.52 ± 7.92<sup>a</sup> | 23.58 ± 4.11<sup>a</sup> | 17.36 ± 1.87<sup>a</sup> |
| 20:20:60         | 7.18 ± 1.09<sup>bc</sup> | 60.19 ± 13.13<sup>c</sup> | 75.96 ± 5.73<sup>c</sup> | 17.34 ± 4.43<sup>cd</sup> | 12.40 ± 1.85<sup>c</sup> |
| 25:25:50         | 6.95 ± 1.14<sup>c</sup> | 62.79 ± 2.85<sup>b</sup> | 82.22 ± 5.46<sup>c</sup> | 21.35 ± 3.73<sup>ab</sup> | 16.34 ± 1.86<sup>ab</sup> |
| 30:30:40         | 7.93 ± 1.96<sup>bc</sup> | 56.45 ± 4.17<sup>d</sup> | 83.91 ± 2.96<sup>bc</sup> | 13.76 ± 2.59<sup>d</sup> | 15.22 ± 0.97<sup>c</sup> |
| 35:35:30         | 8.94 ± 1.13<sup>ab</sup> | 72.59 ± 4.69<sup>ac</sup> | 86.45 ± 2.73<sup>b</sup> | 21.35 ± 1.13<sup>ab</sup> | 15.12 ± 1.80<sup>a</sup> |

Different letters in the same column indicate significant difference at p≤0.05.

**Table 6.** Thiobarbituric acid reactive substances (μg MDA/mL) of oil during frying at 0, 8, 16, 24, and 32 cycles.

| Oil Formulations | Frying cycles |
|------------------|---------------|
|                  | 0  | 8  | 16 | 24 | 32 |
| PO               | 1.95 ± 0.05<sup>b</sup> | 0.78 ± 0.06<sup>cd</sup> | 4.36 ± 0.08<sup>d</sup> | 5.13 ± 0.46<sup>b</sup> | 3.65 ± 0.15<sup>c</sup> |
| RBO              | 0.44 ± 0.34<sup>a</sup> | 0.57 ± 0.08<sup>d</sup> | 10.84 ± 1.11<sup>a</sup> | 6.80 ± 0.11<sup>a</sup> | 9.26 ± 2.76<sup>c</sup> |
| CO               | 2.37 ± 0.35<sup>bc</sup> | 1.55 ± 0.35<sup>bc</sup> | 3.48 ± 0.24<sup>d</sup> | 6.73 ± 1.04<sup>a</sup> | 6.77 ± 0.12<sup>ab</sup> |
| 20:20:60         | 1.63 ± 0.12<sup>c</sup> | 0.94 ± 0.30<sup>cd</sup> | 9.56 ± 0.09<sup>bc</sup> | 3.66 ± 0.22<sup>c</sup> | 2.74 ± 0.57<sup>c</sup> |
| 25:25:50         | 0.15 ± 0.67<sup>c</sup> | 3.07 ± 0.20<sup>c</sup> | 7.06 ± 1.21<sup>c</sup> | 1.19 ± 0.06<sup>d</sup> | 2.76 ± 0.22<sup>c</sup> |
| 30:30:40         | 0.94 ± 0.06<sup>d</sup> | 0.13 ± 0.05<sup>d</sup> | 8.49 ± 1.04<sup>bc</sup> | 1.71 ± 0.40<sup>d</sup> | 3.44 ± 0.30<sup>bc</sup> |
| 35:35:30         | 0.82 ± 0.01<sup>d</sup> | 2.02 ± 0.86<sup>b</sup> | 7.80 ± 0.58<sup>e</sup> | 3.67 ± 0.49<sup>e</sup> | 4.82 ± 1.12<sup>b</sup> |

Different letters in the same column indicate significant difference at p≤0.05.
Tropical Oil Blending and Their Properties Changes during Deep Frying

Palm oil and coconut oil are suitable for use as frying oils because they have high saturated fatty acids, which are more stable to heat than unsaturated fatty acids. The main components of rice bran oil were palmitic acid, oleic acid, and linoleic acid. These results comply with the research data previously reported that rice bran oil contains palmitic acid, oleic acid, and linoleic acid in ranges of 13.9–22.1%, 35.9–49.2%, and 27.3–41.0%, respectively (19). When considering the increased saturated fatty acids in the blended oils, most of them were found to be medium chain fatty acids, especially lauric acid which is the fatty acid found in coconut oil. Research shows that lauric acid is linked to many health benefits. It is efficiently absorbed into the portal circulation directly, so has rapid access to the liver. It is thus unlikely to promote obesity via direct storage in adipose tissues (20). Moreover, accumulating evidence indicates that lauric acid, along with other medium chain fatty acids, plays an important role in the intracellular signaling and contributes to the regulation of cell metabolism (21). In addition, the oil blends with higher ratios of rice bran oil had higher proportions of unsaturated fatty acids. Many reports reveal that diets rich in polyunsaturated fatty acids promote reduced levels of total cholesterol and LDL cholesterol in the blood (22).

Antioxidants found in the oils include α-tocopherol.

### DISCUSSION

The oil fatty acid composition analysis suggests that palm oil and coconut oil are suitable for use as frying oils because they have high saturated fatty acids, which are more stable to heat than unsaturated fatty acids. The main components of rice bran oil were palmitic acid, oleic acid, and linoleic acid. These results comply with the research data previously reported that rice bran oil contains palmitic acid, oleic acid, and linoleic acid in ranges of 13.9–22.1%, 35.9–49.2%, and 27.3–41.0%, respectively (19). When considering the increased saturated fatty acids in the blended oils, most of them were found to be medium chain fatty acids, especially lauric acid which is the fatty acid found in coconut oil. Research shows that lauric acid is linked to many health benefits. It is efficiently absorbed into the portal circulation directly, so has rapid access to the liver. It is thus unlikely to promote obesity via direct storage in adipose tissues (20). Moreover, accumulating evidence indicates that lauric acid, along with other medium chain fatty acids, plays an important role in the intracellular signaling and contributes to the regulation of cell metabolism (21). In addition, the oil blends with higher ratios of rice bran oil had higher proportions of unsaturated fatty acids. Many reports reveal that diets rich in polyunsaturated fatty acids promote reduced levels of total cholesterol and LDL cholesterol in the blood (22).

Antioxidants found in the oils include α-tocopherol.

### Table 7. Viscosity (Cps) of oils before and after frying for 32 cycles and their % viscosity increase.

| Oil Formulations | Viscosity (Cps) Before | Viscosity (Cps) After | % Viscosity increase |
|------------------|------------------------|-----------------------|---------------------|
| PO               | 88.28±0.33             | 90.78±0.10            | 2.83±0.47<sup>d</sup> |
| RBO              | 85.12±0.15             | 88.58±0.50            | 4.06±0.78<sup>d</sup> |
| CO               | 68.50±0.31             | 76.52±0.25            | 11.70±0.33<sup>b</sup> |
| 20:20:60         | 82.20±0.82             | 85.10±0.30            | 3.53±1.39<sup>d</sup> |
| 25:25:50         | 81.72±0.50             | 90.71±0.72            | 11.01±0.86<sup>c</sup> |
| 30:30:40         | 76.59±0.20             | 90.56±0.90            | 18.24±1.01<sup>b</sup> |
| 35:35:30         | 71.45±0.90             | 89.85±0.18            | 25.76±1.34<sup>a</sup> |

Different letters in the same column indicate significant difference at <sup>p</sup>≤0.05.

### Table 8. Color coordinate (L*, a*, b*) values of oils before and after frying for 32 cycles.

| Oil Formulations | L* Before | L* After | a* Before | a* After | b* Before | b* After |
|------------------|-----------|----------|-----------|----------|-----------|----------|
| PO               | 63.43±0.22| 59.13±0.06| -3.53±0.10| -3.59±0.38| 12.57±0.27| 36.62±0.02|
| RBO              | 62.89±0.21| 62.45±0.43| -3.70±0.10| -3.57±0.29| 12.49±0.22| 26.53±0.16|
| CO               | 64.39±0.13| 62.41±0.30| -1.26±0.45| -2.92±0.50| 4.10±0.07 | 13.74±0.20|
| 20:20:60         | 64.10±0.79| 60.98±0.26| -5.15±0.32| -3.72±0.28| 19.00±0.56| 32.08±0.36|
| 25:25:50         | 64.35±0.17| 62.22±0.16| -4.69±0.35| -3.73±0.15| 17.02±0.61| 26.27±0.13|
| 30:30:40         | 64.60±0.26| 61.68±0.63| -3.68±0.35| -3.70±0.16| 14.57±0.33| 29.23±0.40|
| 35:35:30         | 64.20±0.16| 62.57±0.24| -4.07±0.50| -3.90±0.43| 15.91±0.30| 30.66±0.19|

Different letters in the same column indicate significant difference at <sup>p</sup>≤0.05.

CIE L*, a*, b* color coordinates were used to determine the degree of lightness (L*), redness-greenness (+ or −a*), and yellowness-blueness (+ or −b*). Table 8 shows the color values of the oils before and after frying. As expected, the increased L* values and decreased b* values of the oils after frying were observed, reflecting the darkening of the oils due to thermal oxidation reactions as well as the dissolved pigments from fried foods or Maillard browning reaction (18).

### Sensory evaluation

In this study, a 9-point hedonic scale was used to measure the acceptability of sensory characteristics of French fries cooked in different oil formulas. As shown in Table 9, there was no significant difference in color, odor, texture, and overall desirability score for the fries prepared in all the frying oils.
and γ-oryzanol. α-Tocopherol is the most common and biologically active form of vitamin E which is a natural antioxidant. γ-Oryzanol is a ferulic acid ester of sterols naturally found in rice bran oil. It is well-known for its antioxidant activity. Besides, γ-oryzanol exerts a wide range of biological activities, including cholesterol-lowering, anti-inflammatory, anti-cancer, and anti-diabetic effects (23). It has previously been reported that rice bran oil contains γ-oryzanol, ranging from 0.2–2.9% depending on the method of extraction, rice variety, weather, and area of cultivation (24, 25).

Free fatty acids (FFA) are produced by the hydrolysis of oils and fats in the presence of enzymes, heat, and moisture. The FFA level usually increases during storage or processing, such as heating or frying depending on time, temperature, and moisture content. FFA are more susceptible to oxidation compared to intact triacylglycerol, so the FFA value is an important parameter for oil quality assessment. Moreover, the high FFA content also negatively affects the physical properties of the oils, such as lowering the surface tension and smoke point. According to the Codex standard for fats and oils, the FFA value of refined oil should be less than 0.6 mg KOH/g oil (12).

Table 9. Hedonic scores of French fries fried in different oils.

| Blended oils | Sensory attributes |
|--------------|--------------------|
|              | Color<sup>aa</sup> | Odor<sup>aa</sup> | Flavor | Texture<sup>aa</sup> | Overall<sup>aa</sup> |
| PO           | 7.00±1.14          | 6.46±1.76          | 5.94±1.39<sup>ab</sup> | 5.96±1.75          | 6.16±1.53          |
| RBO          | 6.82±1.57          | 6.52±1.67          | 6.32±1.71<sup>a</sup> | 6.22±1.64          | 6.52±1.59          |
| CO           | 7.00±1.18          | 6.50±1.76          | 6.04±1.54<sup>ab</sup> | 5.88±1.61          | 6.52±1.09          |
| 20 : 20 : 60 | 7.94±9.50          | 6.02±1.56          | 5.96±1.47<sup>ab</sup> | 5.78±1.63          | 6.40±1.49          |
| 25 : 25 : 50 | 6.66±1.55          | 6.42±1.39          | 5.40±1.78<sup>b</sup> | 5.60±1.70          | 6.20±1.31          |
| 30 : 30 : 40 | 6.86±1.28          | 6.26±1.45          | 5.78±1.67<sup>ab</sup> | 5.72±1.57          | 6.32±1.28          |
| 35 : 35 : 30 | 6.86±1.41          | 6.52±1.28          | 6.00±1.44<sup>ab</sup> | 5.56±1.86          | 6.24±1.44          |

Different letters in the same column indicate significant difference at <i>p</i> ≤ 0.05.<n>aa</n> means not significantly different at <i>p</i> > 0.05.

Therefore, total polar compound contents (TPC) are usually used as an indicator for oil deterioration during frying. Many countries have established maximum TPC allowances in the range of 20–27% (31). The TPC contents of the oil in this study did not exceed the maximum limit of allowance of 27% after 8 h of continuous frying. At the 32 cycles of frying, the TPC of blended oils were comparable with the palm oil. This suggests that blended oils showed acceptable oxidative stability compared with the palm oil alone. The antioxidant components such as α-tocopherol and γ-oryzanol might play role in protecting oil blends from thermal deterioration during frying (10).

Peroxide value (PV) is an indicator of the early stage of lipid oxidation. It was observed that the PVs of all fresh oils were in agreement with the maximum Codex standard PV (10 meq O₂/Kg) for vegetable oil (12). The PVs tended to increase during frying due to lipid oxidation. However, lipid hydroperoxides are unstable substances and they simultaneously decompose as secondary lipid oxidation products which involve in rancidity. This led to the continuous decrease of PVs for all the oils, as observed after the sixteenth frying. Moreover, at the sixteenth frying, the blended oils had lower PV compared to the pure oils. Fatty acid composition, α-tocopherol, and γ-oryzanol in the oil blends may have conferred this greater oxidative stability (10).

Thiobarbituric acid reactive substances (TBARs) assay measures the amount of lipid oxidation products, such as aldehydes and ketones which occur during the secondary stage of lipid oxidation. The method of analysis is based on the principle that thiobarbituric acids react with malondialdehyde and form pink complex which absorbs visible light at 532–535 nm. The TBARs of all oils gradually increased during frying until the sixteenth frying, when the TBARs decreased. The oils blended at ratios of 25 : 25 : 50 and 30 : 30 : 40 had the lowest TBARs, meaning they were more stable to lipid oxidation compared to the others. This is potentially due to the balanced proportion of saturated fatty acids and unsaturated fatty acids, as well as high levels of α-tocopherol and γ-oryzanol of these oil blends (8, 10).
Viscosity is a main quality parameter for frying oil. Increasing viscosity is the result of polymerization which occurs during deep frying due to high temperatures which induces cross-linking within the molecule or between molecules of triacylglycerol. Bonding between carbon-carbon or carbon-oxygen-carbon within molecules of fatty acids, or between molecules resulting in the formation of compounds with high molecular weight including cyclic monomers, dimers, and polymers (27). In this study, the increased viscosity was inversely proportional to the amount of palm oil in the oil blends. It is possible that the palm oil contained the lowest saturated fatty acid content (as shown in Table1), thus the oil blends containing higher proportions of palm oil were more stable to the harsh conditions during frying so fewer polymerized compounds were generated. In addition, the high content of α-tocopherol in palm oil could help protect the oil from oxidation (32, 33).

Color is one of the main physical properties of vegetable oils that impacts the consumer’s acceptability. The color of vegetable oils vary greatly depending on their origins. Coconut oil had lighter color intensity with L* of 64.39±0.13, compared to palm oil and rice bran oil (63.43±0.22 and 62.89±0.21, respectively). An increase in color intensity of oils after frying was observed in all oil formulas. The darkening of oils contributes to the formation of oxidation products as well as the Maillard reaction products. Moreover, pigments from foods could leach to the frying oil and affect the color quality. After frying for 32 cycles, the lightness of all blended oils was significantly higher than that of the palm oil. Studies revealed that blending oils with good oxidative stability retarded the darkening process during deep frying (34, 35).

Oil blending is the simplest method that is commercially used not only to improve the physicochemical properties but also to enhance the nutritional characteristics of the oils. The blended oils could be effectively used for industrial applications and for home cooking. This would positively impact on the health of the general population. Compared to other studies, this research provides new oil blends composed of nutritious tropical oils that are economical for the production. The sensory analysis results in this study suggest that the blended oils were as good as palm oil in terms of the sensory qualities of the fried products. Based on the findings in this study, an appropriate blending ratio of rice bran oil, coconut oil and palm oil was at 30:30:40 (v/v/v). Blending oil at this ratio could provide nutritional benefits and oxidative stability with favorable sensory characteristics.

Disclosure of state of COI

The authors declare no conflict of interest.

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