Physicochemical Properties and Potential Food Applications of *Moringa oleifera* Seed Oil Blended with Other Vegetable Oils

Sarafhana Dollah¹, Sabo Muhammad Abdulkarim¹, Siti Hajar Ahmad², Anahita Khoramnia¹ and Hasanah Mohd Ghazali¹

¹ Department of Food Science, Faculty of Food Science and Technology
² Department of Crop Science, Faculty of Agriculture Universiti Putra Malaysia, UPM 43400 Serdang, Selangor DE, Malaysia

Abstract: Blends (30:70, 50:50 and 70:30 w/w) of *Moringa oleifera* seed oil (MoO) with palm olein (PO), palm stearin (PS), palm kernel oil (PKO) and virgin coconut oil (VCO) were prepared. To determine the physicochemical properties of the blends, the iodine value (IV), saponification value (SV), fatty acid (FA) composition, triacylglycerol (TAG) composition, thermal behaviour (DSC) and solid fat content (SFC) tests were analysed. The incorporation of high oleic acid (81.73%) MoO into the blends resulted in the reduction of palmitic acid content of PO and PS from 36.38% to 17.17% and 54.66% to 14.39% and lauric acid content of PKO and VCO from 50.63% to 17.70% and 51.26% to 26.05% respectively while oleic acid and degree of unsaturation were increased in all blends. Changes in the FA composition and TAG profile have significantly affected the thermal behavior and solid fat content of the oil blends. In MoO/PO blends the melting temperature of MoO decreased while, in MoO/PS, MoO/PKO and MoO/VCO blends, it increased indicating produce of zero-trans harder oil blends without use of partial hydrogenation. The spreadability of PS, PKO and VCO in low temperatures was also increased due to incorporation of MoO. The melting point of PS significantly decreased in MoO/PS blends which proved to be suitable for high oleic bakery shortening and confectionary shortening formulation. The finding appears that blending of MoO with other vegetable oils would enable the initial properties of the oils to be modified or altered and provide functional and nutritional attributes for usage in various food applications, increasing the possibilities for the commercial use of these oils.

Key words: *Moringa oleifera* seed oil, blending, physicochemical properties, vegetable oils, solid fat content

1 INTRODUCTION

Increased interest in high oleic oils has been spurred by dietary recommendations favoring high monounsaturated oil². Monounsaturated oils have a cardiovascular benefit which lower the plasma total cholesterol level to further lowering the risk of heart disease³. According to Riveros et al.,³ oleic acid also contributes to a longer shelf life of the product due to its high resistance against oxidation and rancidity. The trend nowadays is to incorporate as much liquid oil as possible into the oil mixtures in order to claim the lowest possible amount of saturated fatty acids, following better spreadability of the products⁴. With a high amount of monounsaturated (oleic) (81.73%) and low polyunsaturated (linoleic) (0.71%) FAs, *Moringa oleifera* seed oil MoO represents an alternative source of superior oil with high stability⁵ and good characteristics toward prevention of cholesterol and heart disease.

MoO, an oil with a peanut-like flavor⁶ and a fatty acid (FA) composition resembling olive oil⁷, has been used extensively as a general culinary, an excellent salad oil and for cooking purposes. However, because it’s high iodine value and low melting point, pure MoO encountered limiting application in food products like margarine and shortenings. These kind of fats can be suitably modified by hydrogenation. However, hydrogenation produces trans-fatty acids which are directly related to many diseases⁸. The food industry is replacing hydrogenation with other alternatives that can give fats and oils the desired functionality⁹. Modification of fats and oils by direct blending has been encouraged recently as it is the simplest and most

*Correspondence to: Hasanah Mohd Ghazali, Department of Food Science, Faculty of Food Science and Technology
E-mail: hasanah@upm.edu.my
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economic method\textsuperscript{4} for modifying oils and fats for specific applications\textsuperscript{7,15}. 

Fats that are able to impart plasticity can be used to modify MoO thermal characteristic and improve its functionality\textsuperscript{16}. Palm stearin (PS), the cheaper high-melting fraction from palm oil, is not used directly for edible purposes due to its low plasticity and incomplete melting at body temperature\textsuperscript{15}. To improve its melting properties, PS may be blended and/or interesterified with fats that have a good melting profile\textsuperscript{30}. Blends of oil that contain PS are commonly used as feed stocks for production of shortenings, especially in tropical countries\textsuperscript{17}. Whereas, palm kernel oil (PKO) and virgin coconut oil (VCO) were selected in order to utilize the beneficial properties associated with medium chain FA (MCFA)\textsuperscript{8,18} as well as the functional properties of VCO\textsuperscript{19,20}. Besides, the presence of the \(\beta\)-prime polymorphic form in PKO which is necessary for a fine structure of products, provides good aeration and creaming properties and helps to give the right mouth feel\textsuperscript{21}. The other selected vegetable oil is PO which is the liquid fraction from palm oil, is not used directly for edible purposes as feed stocks for production of shortenings, especially in tropical countries\textsuperscript{18}. The ground kernels that were then sorted to remove misshappen seeds. Well formed kernels were dried in a convection oven at 60°C for 12 h. PO was purchased from Lam Soon Edible Oil Sdn. Bhd., Malaysia, while VCO was produced from fresh coconut milk purchased from a local wet market. PS and PKO were obtained from Golden Jomalina Foods Industries Sdn. Bhd., Selangor, Malaysia. All solvents and chemicals used in this study were either of analytical purity 99\% or HPLC grade purchased from BDH Laboratories Ltd (St. Louis, California, USA). Individual standards FA methyl esters of caprylic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1), linoleic (18:2), arachidic (C20:0), eicosenic (C20:1), behenic (C22:0) and lignoceric (C24:0) acids, approximately 99% pure, were purchased from Supelco (Sigma-Aldrich Tokyo, Japan). TAG standards (purity 99\%) were obtained from Sigma Aldrich, Inc. (St. Louis, USA).

### 2 MATERIALS AND METHODS

#### 2.1 Materials

Brown, mature \(M.\ \textit{oleifera}\) pods were collected in the Serdang area in Selangor, Malaysia. The seeds were removed from the pods and crushed gently to obtain the seed’s kernels which were then sorted to remove misshappen seeds. Well formed kernels were dried in a convection oven at 60°C for 12 h. PO was purchased from Lam Soon Edible Oil Sdn. Bhd., Malaysia, while VCO was produced from fresh coconut milk purchased from a local wet market. PS and PKO were obtained from Golden Jomalina Foods Industries Sdn. Bhd., Selangor, Malaysia. All solvents and chemicals used in this study were either of analytical purity 99\% or HPLC grade purchased from BDH Laboratories Ltd (Pool, England), Merck (Darmstadt, Germany) and Sigma Aldrich Inc. (St. Louis, California, USA). Individual standards FA methyl esters of caprylic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1), linoleic (18:2), arachidic (C20:0), eicosenic (C20:1), behenic (C22:0) and lignoceric (C24:0) acids, approximately 99% pure, were purchased from Supelco (Sigma-Aldrich Tokyo, Japan). TAG standards (purity 99\%) were obtained from Sigma Aldrich, Inc. (St. Louis, USA).

#### 2.2 Methods

##### 2.2.1 Extraction of MoO

MoO was extracted from dried \(M.\ \textit{oleifera}\) kernels that had been ground into a fine powder using a Waring blender Model 32BL 80 Dynamic Corpation of America, New Hartford, Connecticut, USA. The ground kernel (500 g) was placed in a cellulose filter paper (Whatman No. 1) cone and oil was extracted using light petroleum ether (b.p 40-60°C) in a 5 L Soxhlet extractor for 8 hours\textsuperscript{6,22}. The solvent was then evaporated off using a rotary evaporator Model N-1 (Eyela, Tokyo Rikakikal Co., Ltd., Japan) and the recovered oil was heated in a convection oven at 60°C for 1 hour to remove residual solvent. The oil was then flushed with 99.9\% nitrogen and stored at \(-20°C\) until further use. The crude oil was used without further refining. The free fatty acid content was determined to be 0.56\%.

##### 2.2.2 Production of VCO

VCO was produced using the natural fermentation method\textsuperscript{23}. One kilogram of fresh coconut milk was placed in a 2 L beaker, covered with aluminum foil and left standing at room temperature (25-27°C) for 24 hours for natural fermentation to take place. The upper layer (oil layer) was then filtered through a filter paper (Fisher QC100, Fisher Scientific, Leicestershire, UK) and heated at 60°C in a convection oven overnight to remove extra moisture in the oil. The oil was kept in \(-20°C\) for analysis. The free fatty acid value was determined to be 0.23\%.

##### 2.2.3 Blending of MoO with other edible vegetable oils

MoO, PO, PKO and VCO were completely melted at 60°C prior to use. In this study, MoO was blended with PO, PS, PKO and VCO separately at ratios of 70:30, 50:50 and 30:70 by weight (w/w). The oil blends were thoroughly mixed and then heated at 60°C for an hour to obtain homogenous mixtures. The mixtures were stored at \(-20°C\) when they were not used for analysis.

##### 2.2.4 Physicochemical characterization of oils and blends

##### 2.2.4.1 Fatty acid (FA) composition

The FA composition was determined after conversion of the oil samples into FA methyl esters (FAMEs) prepared by adding 950 µL of n-hexane to 50 µg of oil followed by 50 µL of sodium methoxide using the method of Cocks and van Rede\textsuperscript{24}. The mixtures were vortexed for 5 s and allowed to settle for 5 min. The top layer (1 µL) was injected into an ELITE-5(30 m length, 0.25 mm internal diameter and 0.25 µm film thickness, Perkin Elmer, USA) capillary column placed in a Model Clarus 500 Perkin Elmer gas chromatograph (Perkin Elmer Incorporated, Shelton, Con-
necticut, USA) equipped with a flame-ionization detector to obtain FAMEs peaks. The detector temperature was 240°C and the column temperature was 130°C held for 0.5 min, after which the temperature increased at the rate of 10°C/min to 240°C and then held for 5 min. The total run time was 20.5 min. Individual peaks of FAMEs were identified by comparing their retention times with those of standards. The relative concentration of individual FAs was calculated using the peak areas of FA species to the total peak areas of all the FAs in the oil sample.

2.2.4.2 Free fatty acid content (FFA), iodine value (IV) and saponification value (SV)

The FFA, IV and SV were determined using the AOAC (1984) standard analytical methods.

2.2.4.3 Triacylglycerol (TAG) profile

The TAG profiles of the oil samples were obtained by injecting approximately 10 µL of oil samples (10% in acetone, v/v) into a reversed-phase high performance liquid chromatograph (HPLC) comprising a Waters Alliance HPLC (Waters Corporation, Milford, Massachusetts, USA) equipped with a separation module (Waters Model 2695), an auto-injector and a refractive index detector (Waters Model 2414). The TAG were separated using a commercially packed RP-18 column (250 × 4 mm) with particle size 5 mm (Merck, Darmstadt, Germany) held in a column oven set at 35°C. Elution of TAG from the column was achieved using a mixture of acetone/acetonitrile (63.5:36.5) as the mobile phase at a flow rate of 1 mL/min. The total run time was 100 min. TAG peaks were identified based on the retention time of available TAG standards and the results of peak areas produced by the data integrator (Empower-Pro Version 2002, Waters Corporation, Milford, Massachusetts, USA) were used to quantify the component based on relative percentages.

2.2.4.4 Thermal properties

The thermal properties of the oil samples were investigated by differential scanning calorimetry (DSC) using a Perkin-Elmer Diamond DSC (Shelton, Connecticut, USA) based on the procedure described by Abdulkarim et al. The instrument was calibrated using indium and zinc. The purge gas used was 99.9% nitrogen with a flow rate of 100 mL/min and a pressure of 20 psi. Samples (5-8 mg that had been completely melted at 60°C) were sealed in aluminium volatile DSC pans and placed in the instrument’s sample chamber. An empty DSC pan was used as the reference. The sample chamber was heated to 70°C and held for 2 min to erase crystal memory in the oil. It was then cooled to −60°C at the rate of 10°C/minute, and held at −60°C isothermally for 2 min and heated from −60°C to 70°C at the rate of 10°C/minute. The heating and cooling thermograms were recorded and the values for onset, peak and endset temperatures tabulated. Onset temperature indicates the temperature for melting process starts and endset temperature indicates the complete melting temperature of the oil.

2.2.4.5 Prediction of solid fat content

The solid fat contents (SFC) of all samples at different temperatures were calculated from their thermal profile according to Adhikari et al. Each DSC melting thermogram was divided into different temperature sectors (0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 55°C) and the total crystallization energy (J/g) at each temperature was then converted into percentage (% fat) based on the following equation:

\[(%) \text{ Fat} = \frac{\text{Partial (J/G)}}{\text{Total (J/G)}} \times 100\]

2.2.4.6 Statistical analysis

Statistical analysis was carried out using MINITAB 14 (Minitab Inc., State College, PA, USA) by subjected all data obtained to univariate analysis of variance (ANOVA) to determine the significant differences among samples followed by Turkey’s pairwise test significant defined at p < 0.05. All measurements were carried out in triplicate and reported as the mean and standard deviation of independent trials.

3 RESULTS AND DISCUSSION

3.1 FA composition

The FA composition of MoO, PO, PS, PKO, VCO were presented in Table 1 and the binary mixtures of MoO with each mentioned oil in ratios of 70:30, 50:50 and 30:70 w/w were obtained by calculating the weighted average for each fatty acid. MoO contained high amounts of oleic acid (C18:1, 81.73%) which is higher than those reported by Abdulkarim et al. in the range of 67.9-74.4%. PO was found to be abundant in oleic acid (C18:1, 46.86%) followed by palmitic acid (C16:0, 33.14%) and VCO contained high amounts of oleic acid (C18:1, 50.63%) which is higher than those reported by Naghshineh et al. in the range of 67.9-74.4%. PS contained high amounts of oleic acid (C18:1, 72.76%) which may be considered having better oxidative stability and characteristics compared to PO alone and other MoO/PO blending ratio. Naghshineh et al. reported that the partial replacement of C16:0 with C18:1 resulted in the least increment in total polar content (TPC) and viscosity of the oil blend.
after frying. High oleic acid oils have been proven to be high resistant to thermal oxidative rancidity during frying.\(^5\) Anwar \textit{et al.}\(^9\) also demonstrated the important role of MoO in appreciable oxidative stability improvement of oil blends with linoleic rich oils. As food habits of most of the Malaysian population are based on deep fried foods, MoO/PO blends that are locally abundant sources would be excellent options for oxidative-resistant oils.

With MoO/PS blends, as the PS content in the blend formulations were increased, the relative concentrations of saturated FAs were found to increase. The saturated FA that experienced a major increment was C16:0 which increased up to 38.39\(\%\) and unsaturated FA, C18:1 was decreased up to 49.12\(\%\) in 30:70 MoO/PS blend. As both PKO and VCO had similar FA, their binary mixtures with MoO showed little diversity. Blending led to major increments in the relative concentrations of capric, caprylic, lauric and myristic acid, and caused small increases in linoleic acid concentration as the quantity of PKO in the blend is increased. The FA that experienced a major decrease in both MoO/PKO and MoO/VCO blends is the C18:1. Although blending MoO with PKO or VCO increased the saturated FA in the blends, but it is considered as healthy oil due to the incorporation of MCFAs as demonstrated by Nevin and Rajamohan\(^{26}\). The right mixture of MoO and PKO or VCO may produce an oil blend that is rich in both MCFA as well as monounsaturated FA (C18:1). Thus, the nutritional quality of MoO is improved by enriching it with MCFA and widens its applications in foods and pharmaceuticals. Such an oil does not exist in nature, unless one considers a palm oil-palm kernel oil mixture (26.0\% oleic acid and 25.4\% lauric acid in a 50:50 mixture) as a single product from one source, namely oil palm \textit{(Elaeis guineensis Jacq.)}. Lauric acid is easily utilized by the body to produce energy rather than being stored as a body fat\(^{27}\) as well as its antimicrobial property\(^{28}\). High lauric oils have been using in the clinical area for treatment of fat malabsorption patients\(^{29}\). Many researchers have attempted to incorporate MCFAs into oleic oil to produce oil with metabolic benefits and effect of preventing various cardiovascular diseases. Chandhapuram and Sunkireddy\(^{30}\) and Lai \textit{et al.}\(^{31}\) reported a study on incorporation of MCFA into palm olein, while, Fomuso and Akoh\(^{32}\) reported on incorporation of MCFA into olive oil. The increment and decrement of fatty acids can be related to the changes in physicochemical and functional properties of the binary mixtures\(^{33}\).

### 3.2 Free fatty acid (FFA) content, Iodine value (IV) and Saponification value (SV)

The chemical composition of pure oils such as FFA contents are shown in Table 1. The refined, bleached and deodorized PO, PS and PKO contained much lower levels of FFA in compared to those in manually extracted MoO and

<table>
<thead>
<tr>
<th>Samples</th>
<th>C8:0</th>
<th>C10:0</th>
<th>C12:0</th>
<th>C14:0</th>
<th>C16:0</th>
<th>C16:1</th>
<th>C18:0</th>
<th>C18:1</th>
<th>C18:2</th>
<th>C20:0</th>
<th>C20:1</th>
<th>C22:0</th>
<th>C24:0</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoO</td>
<td>2.97</td>
<td>1.12</td>
<td>3.97</td>
<td>81.73</td>
<td>0.71</td>
<td>2.75</td>
<td>1.3</td>
<td>4.86</td>
<td>0.6</td>
<td>84.86</td>
<td>0.56</td>
<td>67.46</td>
<td>188.7</td>
</tr>
<tr>
<td>PS</td>
<td>0.73</td>
<td>36.38</td>
<td>1.3</td>
<td>2.97</td>
<td>3.01</td>
<td>5.6</td>
<td>27.0</td>
<td>1.5</td>
<td>4.86</td>
<td>0.6</td>
<td>84.86</td>
<td>0.56</td>
<td>67.46</td>
</tr>
<tr>
<td>PKO</td>
<td>1.14</td>
<td>54.66</td>
<td>1.3</td>
<td>2.97</td>
<td>3.01</td>
<td>5.6</td>
<td>27.0</td>
<td>1.5</td>
<td>4.86</td>
<td>0.6</td>
<td>84.86</td>
<td>0.56</td>
<td>67.46</td>
</tr>
<tr>
<td>VCO</td>
<td>3.96</td>
<td>3.45</td>
<td>50.63</td>
<td>16.33</td>
<td>8.36</td>
<td>1.88</td>
<td>13.35</td>
<td>2.02</td>
<td>1.83</td>
<td>6.21</td>
<td>0.23</td>
<td>1.31</td>
<td>247.85</td>
</tr>
</tbody>
</table>

Table 1 Chemical composition of Moringa oleifera seed oil and selected vegetable oils in pure form.
BLENDING of Moringa oleifera seed oil with other vegetable oils

VCO. IV is a reasonable measure of the degree of unsaturation of oil\(^1\). The IV of MoO was found to be 67.46 g I/100g oil which was significantly higher \((p<0.05)\) compared to PO (61.04 g I/100g oil), PKO (21.32 g I/100g oil), PS (19.85 g I/100g oil) and VCO (8.30 g I/100g oil) due to its degree of unsaturation (Table 1). Chong\(^2\) reported that PS has IV ranging from 20 g I/100g for hard stearin and to about 50 g I/100g for soft stearin. From the results, the PS under study can be classified as hard stearin. Generally, the IV of MoO was significantly \((p<0.05)\) decreased when blended with other oils especially when the proportion of MoO in the mixtures was lower indicating higher degree of saturation blends were produced. In general, PS is a source of fully natural hard component that is used for making edible fat products such as margarine, shortening and pastry. Combining liquid oils and PS is used to obtain fat mixtures with better spreadability needed in products like margarine and shortening\(^2\) with modified physical and chemical properties.\(^3\) The IV of the extracted VCO was comparable to the IV reported by Marina et al.\(^4\) \((4.47 \text{ to } 8.55 \text{ g I/100g})\) for commercial Malaysian and Indonesian VCO but higher than reported by Dia et al.\(^5\) \((4.35 \text{ to } 6.85 \text{ g I/100g})\). Coconut oil including VCO contains approximately 90% saturated FAs that make it low in IV.

The SV (Table 1) is a measure of the average molecular weight of all the FA present in oil. Higher SV indicates the presence of shorter types of FAs on the glycerol backbone. As compared to other vegetable oils, VCO has a very high SV \(260.74 \text{ mg KOH/g oil}\). SV of PKO is 247.85 \text{ mg KOH/g oil} followed by PS \(201.88 \text{ mg KOH/g oil}\), PO \(194.73 \text{ mg KOH/g oil}\) and MoO \(188.70 \text{ mg KOH/g oil}\). Abdulkarim et al.\(^6\) reported that SV for MoO was 163 to 164 \text{ mg KOH/g oil}.

SV for PO, PS and PKO was comparable with Codex\(^8\) value range. Results for oil blends obtained show that the SV for MoO/PS blends decreased significantly \((p<0.05)\) with increased amount of PS. For MoO/PS and MoO/VCO blends the SV increased significantly \((p<0.05)\) when the amount of PKO and VCO added in the oil mixture were increased. For MoO/PO blends, the results show that there were no significant differences \((p>0.05)\) in SV.

3.3 Triacylglycerol (TAG) profile

Figure 1 shows the main individual triacylglycerols that make up the MoO, PO, PS, PKO and VCO raw materials along with 50:50 w/w binary blends as representative. The most prominent TAG in MoO was triolein (OOO), followed by POO + SOL, SOO, OOA, POL and OOGa and with small amounts of OOL similar to what Abdulkarim et al.\(^6\) reported. The TAG composition of PS is characterized by a high contents of POO, PPO, POL and PPL, followed by OOO, MPL, PSO, MMP, SOO and a small quantity of MMM and OOL. PS has almost all the TAG that can be found in PO except that it has two other TAGs comprising PPP and PPS, which are not found in PO. On the other hand, PKO and VCO were mainly composed of saturated medium chain FAs that mainly exist as fully saturated TAGs such as CCLA, CLaLa, LaLaLa, LaLaM, LaMM and LaPM. The difference in PKO and VCO TAG profiles would be due to the proportion of faster eluting TAGs in VCO were much greater than PKO. The TAG profile obtained for PKO was found to be similar to that reported by Chen et al.\(^8\).

Figure 1 (blends) shows that there were changes in the heights of some TAG peaks when MoO and PO were blended. MoO has a unique TAG profile which differs from PO. In general, the MoO/PO 50:50 blend contained three major TAGs rich in oleic acid which were POO + SOL, OOO and PPO. Olive oil which has high concentration of OOO, POO + SOL and OLL is almost similar to the MoO/PO blend\(^6\). Extra virgin olive oil (72.12% oleic acid) and hazelnut oil blend 70:30 and 60:40 was reported to consist mainly of OOO, OLO, OLL + OLP, OOP + SLO and OLP\(^9\). During blending, as the proportion of PO into MoO increased from 30% to 50% and 70%, there were decrements of OOO, SOO, OOA and OOGa peak heights. The degree of decrement depended on the blend ratio. TAGs that experienced an increment of peak heights were POO + SOL, PPO, POL, PPL and OOL. This is due to high amounts of TAG that contain palmitic acid exist in PO and high amounts of triolein (OOO) in MoO. PO contained 46.86% of oleic acid but not much in the form of OOO. MoO/PO 70:30 blend produced oil with richer in tri-unsaturated (OOO), less di-saturated (PPL and PPO) than was the 50:50 and 30:70 blend. This blend is expected to have the best stability and resistance towards oxidation because oleic acid has high resistance towards oxidative rancidity. Therefore, it is suitable for frying\(^10\) as well as high oleic cosmetic formulations\(^4\). According to Naghshineh et al.\(^11\), partial replacement of PO with 25% and 50% of olive oil produces an oil blend with higher stability to oxidative rancidity compared to regular PO.

As shown in Fig. 1, MoO/PS blend 50:50 contained three major TAGs rich in oleic acid which were POO + SOL, OOO and PPO. Other TAGs were SOO, PSO, OOA, POL, PPL, MMP, PPP, MPL, PPL, PPO, OOL, OOA and OOGa. During blending, as the concentration of PS was increased from 30% to 50% and 70%, the relative concentrations of MPL, OOL, POL, PPL, PPO and PSO increased. This is due to the high amounts of palmitic and linoleic acids in PS that contributed to the increase in the concentrations of palmitic acid and linoleic acid containing TAG species, compared to in MoO. It is observed that palmitic acid progressively increased once the quantity of PS incorporated with MoO increased, whereas the opposite effect was found for oleic acid. These fatty acids contributed to the formation of TAG species such as PPO and POL which in this study showed a progressive increment when the proportion of added PS was increased. The TAGs that showed a major peak decrease in concentration were MMP, OOO and OOA. Saadi et

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al.\textsuperscript{13} examined PO/PS blends and found that the PPO/POP content of the blends increased progressively as the level of PS increased. In another study, Tanaka \textit{et al.}\textsuperscript{42} reported that POP, SOS or SSS are the components of the growing crystals in margarines prepared from palm oil and soybean oil although PPP will be the first to crystallize to form a granular crystal. Since MoO/PS blends shows the presence of all these TAGs, it can be considered suitable to be used as a fat stock for margarine formulation.

\textbf{Figure 2} also represents the TAG profiles of MoO/PKO 50:50 blends (as representative). As expected, at a high MoO blend ratio, the proportion of OOO, POO + SOL, SOO and other TAG, that are representatives of MoO, were high. On the other hand, as the proportion of PKO increased, the proportion of the above mentioned TAG decreased correspondingly while the concentration of medium chain TAG, such as CCLa, CLaLa, LaLaLa and LaLaM, increased instead. TAG composition that changes during blending is
very much influenced by the type of TAG profile of the native oil. When MoO was blended with PKO, some of the unsaturated TAG, e.g. LaPO and OOL or MMO and POL of PKO merged and appeared at the same retention time making it difficult to distinguish which TAG were actually experienced concentration changes.

The major TAG in all the three MoO/VCO blends consisted of CCLa, CLaLa, LaLaLa, LaLaM, LaMM, OOO, POO + SOL, SOO and LaPM. Like blending with PKO, as the proportion of MoO decreased and VCO increased, the peak concentration of OOO, POO + SOL, OOGa, SOO, PSO, OOA and POB decreased correspondingly while most of medium chain TAG such as CCLa, CLaLa and LaLaLa increased. Although PKO and VCO are both lauric oils, they however, have different TAG profiles (Fig. 1). In MoO/VCO 70:30 blend, the highest TAG peak was OOO followed by CCLa,
CLaLa and LaLaLa. Compared to MoO/PKO 70:30 blend, the highest TAG peak was LaLaLa followed by OOO, LaLaM, CCLa and CLaLa. In MoOVCO blend, as the proportion of VCO increased, the CCLa, CLaLa, LaLaLa, LaLaM and LaMM peaks start to increase and become higher than OOO. In MoOVCO 30:70 blend, the highest TAG peak was CCLa. The observation was different for MoO/PKO of the same blend ratio where the highest TAG peak was LaLaLa. Chnadhipuram et al.\textsuperscript{30} reported on the incorporation of MCFA into PO and found that the MCFA-rich PO has a chance to be used in therapeutic foods application. Tsuji et al.\textsuperscript{27} reported that medium chain triacylglycerol (MCT) intake reduced body weight and body mass index (BMI) similar to the findings made by St-Onge and Bosarge\textsuperscript{45} who found these compounds more effective than olive oil. Blending MoO with PKO and VCO enriches the TAG composition of MoO with MCT, its nutritional and functional qualities are improved widening its applications in food and pharmaceuticals. In addition to MCT incorporation into the blends, VCO considered as a functional food with many healing benefits as described by Marina et al.\textsuperscript{19}.

3.4 Thermal property

Figure 2 shows the melting and crystallisation curves of MoO and its blends with PO, PS, PKO and VCO. Figure 2a shows that MoO has one major melting peak and two small shoulder exothermic peaks. In MoO/PO blends as the proportion of PO increased, the two shoulder peaks (Peak A1 and Peak A2) in the melting chromatograms of MoO became smaller and at MoO/PO 30:70 w/w ratio, another peak (Peak D2) appeared next to the major peak (Peak D3) due to presence of TAG species as the effect of blending. The end temperature of the MoO decreased from 20.10°C to 14.32°C after adding 30% of PO however, by increasing the proportion of PO no more significant (p > 0.05) decrease occurred. The related crystallization thermogram (Fig. 2e) revealed that MoO has a broad low temperature crystallization peak whereas PO has a broad of high temperature crystallization peak. The low temperature crystallization peak (Peak A1) was found to shrink and the high temperature crystallization peak (Peak A2) broadened and became more dominant. A shift towards higher melting points occurred after blending MoO/PO due to the incorporation of C16 into the blend which has higher melting point than C18:1 however, the cooling profile revealed sharper and steeper peaks compared to MoO alone indicating the presence of TAGs with a fairly narrow range of melting points generated after blending with PO.

Figure 2b illustrates that PS has five exothermic peaks (Peaks E1-E5). In MoO/PS blends as the percentage of PS increased, Peaks B3, C3 and D4 that represented the high-melting TAG became bigger and more pronounced due to the increased presence of saturated TAG from PS. The melting temperature shifted significantly (p < 0.05) from 43.03°C in MoO/PS 70:30 to 46.79°C for 30:70 blends indicating that harder oil mixtures were formed. The crystallization thermogram (Fig. 2f) shows the increasing size of the TAG that crystallized at a significantly (p < 0.05) higher temperature in the oil blends after the percentage of PS was increased. Contribution of MoO enhanced the spreadability of PS as MoO/PS 70:30 blend could have characteristics suitable for confectionary formulation. As demonstrated by Petrauskaite et al.\textsuperscript{46}, melting points in the range 37.0–41.0°C is suitable for fats applied as commercial shortenings. Binary blend with ratio of MoO/PS 70:30 w/w presented melting point of 43.03°C and this reduction occurred due to the incorporation of MoO into the blend however, at 41°C, less than 1% of solid fat is remained. Thus, this binary mixture could be used as confectionery fats and is especially rich in monounsaturated fatty acids without any trans-fat.

Addition of PKO to MoO broadened the major melting peak (Peak A2) and low melting shoulder peak (Peak A1) of MoO. High melting peaks generated (B2, C2, C3, D2 and D3) and the major melting peak of the MoO/PKO blends shifted towards the higher melting temperature as the proportion of PKO increased due to its higher degree of saturation. VCO has only single endothermic peak (Fig. 2d) and the heating profile of VCO clearly indicates that this oil has a narrower melting temperature range and relatively lower than PKO. Blending MoO with VCO caused the low melting peak (Peak A1) of MoO to broaden and flatten and finally disappeared with increasing proportions of VCO in the blend. In the MoO/VCO 30:70 (w/w) blend, the melting profiles showed that there were only two exothermic peaks (Peak D1 and D2) compared to the MoO/PKO 30:70 (w/w) blend where three exothermic peaks was observed. Moreover, MoOVCO blends (Fig. 2h) have sharper peaks than MoO/PKO blends (Fig. 2g). This probably indicated that binary mixtures of PKO and VCO with MoO had different polymorphs and microstructures. However, the differences in polymorphic forms between MoO/PKO and MoO/VCO blends can be elucidated by using other techniques such as diffractometer and polarised light microscope. The endset temperature of MoO/VCO blends were increased as the proportion of VCO increased however, PKO revealed higher enhancement into the blends. The melting temperatures of MoO/VCO blends show the ability of the oil mixture in liquid form at ambient temperature. The crystallization profiles of MoO/VCO blends (Fig. 2h) show that blending of MoO with VCO caused a shift in the low crystallization peak (Peak A1) towards a higher temperature and emergence of a new exothermic peak (Peaks B2), including an increased presence of higher melting TAGs. PKO and VCO blends with MoO are generally liquid at ambient temperature due to the increasing degree of unsaturation which make them more suitable to be used as salad oil and
frying oils with high levels of monounsaturated and medium chain fatty acids.

3.5 Solid Fat Content

Figure 3 illustrates changes of solid fat content (SFC) before and after blending. Changes in the amount of TAG species after blending are normally accompanied by a change in the SFC, depending on the type of TAG formed \(^{14,45}\). The SFC profiles is considered as the main tool for specifying and selecting fats for food applications, particularly for margarines and shortenings \(^{46}\) as it is responsible for many characteristics including appearance, ease of packaging, spreadability, oiling-out and organoleptic properties \(^{47}\).

The SFC of the binary blends was directly proportional to the addition of MoO to PO, PS, PKO and VCO at all the temperatures considered. The selected vegetable oils in this study, revealed higher SFC% at all temperatures compared to MoO due to their higher degree of saturation. PO gave closer SFC profile with MoO as both are 100% liquid oils at 20°C, contain less than 1% SFC at 15°C and low amount of solid fat at 10°C. Addition of PO in MoO/PO binary blends, increased the % SFC of MoO in all tested temperatures. However they did not meet the requirements to assure minimum plasticity even under refrigeration temperature. Binary blend of 30:70 MoO:PO exhibited significantly low SFC at 10°C (3.6%), precluding its use as a fatty base for plastic fats like margarines and shortenings. MoO/PO binary blends could be considered as frying oil due to their improved oxidative resistance due to the incorporation of MoO which is more stable than PO \(^{48}\). Healthier liquid oil also can be applied in O/W emulsions, such as mayonnaises and salad dressings.

As shown in Fig. 3, in all binary blends, due to the formation of mixed and greater variability TAG with intermediate melting point, the shape of the curves was significantly modified with more linear melting profiles resulting from the blending \(^{49}\). At low temperatures (4-10°C), where SFC gives an indication of the fat’s spreadability, PS, PKO and VCO originally do not offer satisfactory characteristics with SFC values of over 53%. Wassell and Young \(^{46}\), and Ribeiro et al. \(^{50}\) demonstrated that for spreadability at refrigeration temperatures, the SFC should not exceed 32% at 10°C in order to meet the minimum plasticity requirement. MoO significantly improved their plasticity by altering related SFC profiles after blending. The binary blends of 70:30 w/w MoO:PS, MoO:PKO and MoO:VCO are regarded as offering good spreadability at low temperatures with the SFC values of 28.7%, 27.8% and 23.1%, respectively, at 10°C. The product’s stability and its resistance to oiling-out could be characterized in fats with minimum 10% SFC between 20 and 22°C \(^{46}\). The binary blends of MoO:PS 30:70, 50:50 and 70:30 w/w, MoO:PKO 30:70 and 50:50 w/w, MoO:VCO 30:70 w/w fall within this group of fats. Fats with SFC above 20% at 25°C are considered as all-purpose shortening and the hardness of a specific fat is correlated with the percentage of solid fat above 25°C \(^{50}\). MoO:PS with the ratios of 30:70 and 50:50 are regarded as suitable, endowing products with the mentioned application. Adhikari et al. \(^{31}\) formulated zero-trans margarine fat stock with desirable properties from pine nut oil and palm stearin. The SFC less than 1% between 35 and 37°C demonstrate good melting characteristics at body temperature \(^{51}\). MoO/PS 70:30 w/w had 6.5% SFC at 35°C and still 1.4% SFC at 40°C indicating that blending method was not effective enough to induce the satisfactory mouth feel to PS. In addition, this binary blend cannot be used as frying shortening, as demonstrated by Ghotra et al. \(^{52}\), as these compounds should be free of solids at body temperature in

![Fig. 3](image_url) Solid fat content (SFC) diagrams of (a) MoO/PO and their blends (b) MoO/PS and their blends (c) MoO/PKO and their blends (d) MoO/VCO and their blends.
order to avoid the sensation of graininess in the mouth.

SPC value between 15 and 25°C is critical for plastic fat characterization. At 25°C VCO originally was in the liquid form while PKO contained 33% SFC. The plasticity of PKO diminished in MoO:PKO binary blends with low SFC value of 0-4.5%. However, at 15 to 20°C, incorporation of MoO in MoO:PKO and MoO:VCO binary blends assure minimum plastic properties due to the percentage of saturated fatty acids which is still greater than 25–30%. Generally, the plasticity of MoO:PKO and MoO:VCO blends were diminished at ambient temperatures however the plasticity remained and the spreadability enhanced at refrigeration temperatures. Therefore, these blends become more suitable in soft margarine, spread formulation that are healthier due to the high oleic acid and MCTG. Incorporation of PKO into the blends induce desirable property of margarine fat stock as contained mostly beta-prime polymorphic form while VCO due to its functionality. Moreover, MoO/PS blends could be used as bakery shortening as demonstrated by Podmore, for optimum baking performance and structural formation, bakery shortening should consist of a minimum of 20% SFC at working temperature 25°C and a minimum of 5% SFC at high temperature 40°C. Hence, the suitable blends for bakery shortening chosen based on these criteria would be MoO/PS 50:50w/w and 30:70w/w. Latip et al. also successfully applied blending method to produce a bakery shortening using palm based diacylglycerol and sunflower oil. The use of shortening and margarine is growing as they are one of the most flexible basic food ingredients. The produced modified fats offer special functional utility to baking, confectionery, and cooking applications. The modified fats produced in this study, could satisfy a host of both physical functionality and health/nutritional requirements.

4 CONCLUSION

This study has shown that blending of MoO with PO, PS, PKO and VCO is an effective way to modify the physical and chemical properties of the blends. The binary blends of MoO/PS revealed wide range of plasticity with various food application potential. For example, MoO/PS 50:50 and 30:70 w/w found to be suitable for high oleic trans-free fat bakery shortening formulation. MoO:PKO and MoO:VCO binary blends generated plastic fats with good spreadability in refrigerated temperatures and could be applied in high-oleic/MCFA liquid margarine, soft margarine and spread formulations. However, MoO/PO blends could be applied as high stable frying oil and salad dressing. All blends present reasonable amount of monounsaturated fatty acids derived from MoO that has been linked to reduce risk of high cholesterol and heart disease. On the basis of the present findings, it appears that proper blending of high melting point oils with MoO can result in oil blends which could meet nutritional needs with improved plasticity performance for healthy margarine shortening and fat spreads formulation which could be used as an alternative to partially hydrogenated fats. However, other modification methods could further improve the blends’ properties.

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