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Properties and Storage Stability of O/W Emulsion Replaced with Medium-Chain Fatty Acid Oil

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The properties and changes of an o/w emulsion(mayonnaise) as affected by the replacement of long-chain fatty acid oil with medium-chain fatty acid oil were studied. Different ratios of coconut oil (CNO) and rice bran oil (RBO) (0:100, 10:90, 20:80, 30:70 and 40:60 (v/v)) were blended as the oil base for the study. The highest replacement of RBO with CNO in an o/w emulsion that could be achieved with minimal change of sensory properties was 30%. The Emulsion Stability Index and oil-phase crystallisation temperatures of mayonnaise with RBO alone and with 30% CNO replacement did not change when stored at 30±2°C for 4 weeks. The droplet size of the mayonnaise containing only RBO increased, possibly due to droplet coalescence. In contrast, the droplet size of the mayonnaise with CNO:RBO=30:70 did not change during storage.

INTRODUCTION

Medium-chain fatty acids (MCFAs) are composed of saturated fatty acids with 6 to 12 carbons. Sources of natural medium-chain triglycerides (MCTs) include palm kernel and coconut oils, milk and butter. MCTs provide less energy than triglycerides composed of mainly long-chain saturated fatty acids (LCTs) (8.4 *vs*. 9.2 kcal/g). They also have lower melting points and smaller molecular sizes than LCTs. Moreover, they are liquids at room temperature [Marten *et al*., 2006]. Recent studies have demonstrated the potential of MCTs to reduce fat mass in rats [Han *et al*., 2003] and adiposity in overweight men [St-Onge *et al*., 2003]. Down-regulation of the adipose gene caused the reduction in fat mass [Marten *et al*., 2006]. The MCTs increased energy expenditure and fat oxidation [Alexandrou *et al*., 2007; Clegg, 2010; Montgomery *et al*., 2013]. Daily MCT oil intake (40 g/day for a month) does not result in the accumulation of fat in the liver [Nasaka *et al*., 2002]. Including MCTs in patients' diets led to a reduction in body weight without adverse effects on their metabolic risk [Mumme & Stonehouse, 2015; St-Onge & Bosarge, 2008]. LCTs might cause problems in patients with metabolic syndromes, whereas MCTs play an important role in the dietary treatment of malabsorption syndrome. MCTs are rapidly hydrolysed and can be absorbed directly through the liver *via* the portal vein. MCFAs can be used as an energy source without requiring the use of the carnitine transport system in mitochondria [Nagao & Yanagita, 2010]. MCT/LCT emulsions were used to extract a local anaesthetic from human serum *in vitro* and reduced the risk of hepatic dysfunction more effectively than LCTs alone [Ruan *et al*., 2012; Abteilung & München-Schwabing, 1988]. Several studies have compared the effects of MCFAs and LCFAs in the diet [Wein *et al*., 2009; Trevizan *et al*., 2010; De Vogel-van den Bosch *et al*., 2011a,b; Wycherley *et al*., 2012]. An MCFA and LCFA oil produced from MCTs and edible vegetative oils has also been evaluated for safety [Matulka *et al*., 2006; Ma *et al*., 2015]. The droplets and rheology of o/w emulsions based on soybean and palm kernel olein oil blends were characterised, and their stability was determined [Hayati *et al*., 2007, 2009a,b]. To our knowledge, studies of the effects of the MCT:LCT ratio on the physical, chemical, microbiological and sensory properties of o/w mayonnaise during storage are limited. In this work, coconut and rice bran oils were used as the oil base in o/w mayonnaises. The main MCFA in coconut oil is lauric acid (45–53 wt%), whereas the main LCFAs in rice bran oil are oleic acid (35–50 wt%) and linoleic acid (29–45 wt%) [Gunstone, 2011]. The effects of the MCT:LCT ratio on the properties and storage stability of the o/w mayonnaise were studied. The results help to elucidate the effects of replacing LCTs with MCTs in an oil base on the physical, chemical, microbiological, sensory and stability properties of the oil-in-water emulsion. Moreover, an alternative product for metabolic syndrome patients and weight-concerned patients could be obtained.

MATERIALS AND METHODS

Materials

'Parisut' cold-pressed coconut oil (CNO) and 'King' rice bran oil (RBO) were purchased from Natural Mind Co., Ltd. and Thai Edible Oil Co., Ltd., Thailand, respectively.

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The peroxide values for the CNO and RBO bulk oils were 0.29 and 0.90 meqO_2/kg, respectively. Eggs, vinegar, sugar and table salt were purchased from the same batch at a local supermarket.

Coconut oil and rice bran oil (CNO:RBO) blends and analysis of the edible oil properties

The following CNO and RBO blends were formulated on a volume/volume basis and used as an oil base for mayonnaise: 0:100 (bulk RBO), 10:90 (CNO:RBO=10:90), 20:80 (CNO:RBO=20:80), 30:70 (CNO:RBO=30:70), and 40:60 (CNO:RBO=40:60).

Mayonnaise preparation

Mayonnaise (300 g) was prepared using the coconut and rice bran blended oils as the oil base. The raw material percentages (w/w) were 72% edible oil, 10% egg yolk, 1% table salt, 2% water, 8% sugar and 7% vinegar. The mayonnaise was prepared using a recipe based on preliminary research. The salt, sugar and distilled water were mixed, and the mixture was then added to the egg yolk in a Kenwood mixer (Major Classic KM631, Kenwood, UK). After 3 min of stirring, the edible oils were added to the mixture, which was then vigorously stirred for 12 min. The vinegar was subsequently added to the mixture, and it was gently stirred for 1 min. The finished product (mayonnaise) was placed in a 700-mL glass jar with a screw cap and kept at room temperature (30±2°C) for further study.

Physical, chemical, biological and sensory properties of the edible oils and o/w mayonnaises with bulk oil and oil-blend bases

Physical properties

The mayonnaise colour was determined using the CIELAB method (Minolta CR-400 chroma meter, Konica Minolta, Inc., Osaka, Japan). A texture profile analysis (TPA) was performed using a texture analyser (TA-XT Plus, Texture Technologies, Hamilton, MA) (modified method of Liu *et al*. [2007]). A mayonnaise sample at a height of 50 mm was filled in an acrylic compression disc (35-mm diameter) and then placed in a back extrusion cell. The disc penetrated depth into the sample was adjusted at 30 mm at a 2 mm/s speed and returned at 10 mm/s speed. From the measurement, the firmness (g) and viscosity index (g×sec) were determined.

The oil-phase crystallisation temperature was determined using a differential scanning calorimeter (DSC, Netzsch, model 204 F1 Phoenix, Germany). Ten mg of a fresh emulsion sample was equilibrated at 50°C for 5 min in the DSC cell. The sample was then cooled from 50°C to −70°C at a cooling rate of 10°C/min (modified method of Hayati *et al*. [2009b]).

The mayonnaise microstructure was studied using a light microscope (OlympusBH-2 model, New York Microscopy Company, NY) equipped with a Panasonic WV-CP240/G digital camera (Panasonic Canada Inc., Canada). Before the microscopy experiments, the mayonnaise was diluted with distilled water to a ratio of 1:500 (v/v) mayonnaise:distilled water. The droplet images were captured at room temperature (30±2°C) under 40x magnification.

The Emulsion Stability Index (ESI) was evaluated using the method reported by Mirhosseini *et al*. [2008], with some experimental modifications. A total of 20 mL mayonnaise was filled into a 20-mL graduated test tube; then, the emulsion was stored in quiescent conditions at room temperature (30±2°C) for 4 weeks. The ESI results were obtained from measurements of the initial mayonnaise height (HE), the height of the mayonnaise cream layer (HC), and the height of the mayonnaise droplet-depleted serum phase (HS). The ESI was calculated using the following equation:

$$\mathrm{ESI}(\%) = \frac{(\mathrm{HE} - (\mathrm{HS} + \mathrm{HC}))}{\mathrm{HE}} \times 100$$

Chemical properties

The fatty-acid profile was determined using gas chromatography (GC-2010, Shimadzu, Tokyo, Japan) according to the method of Lepage & Roy [1986]. The fatty-acid profile analysis was performed in two steps: methylation and gas chromatography. For the methylation process, 2 μL of the oil sample were mixed with 2 mL of a 4:1 (v/v) methanol:hexane mixture in a tube. A total of 200 μL of an acetyl chloride solution was added dropwise to the tube, and the mixture was slowly stirred for 1 min. The tube was heated to 100°C for 1 h and then cooled to 25°C. Five mL of a 6% K_2CO_3solution were added to neutralise the mixture, and the tube was centrifuged at 1000 rpm for 5 min at 25°C. An aliquot of the hexane upper phase was removed and injected into the gas chromatograph. The fatty acids were separated using a DB-23 (30 m×0.25mm) capillary column with a film thickness of 0.25 μm. A flame ionisation detector (FID) was employed under the following conditions :a temperature of 300°C, an N_2/air makeup gas, a makeup flow rate of 30 mL/min and an H_2 flow rate of 40 mL/min (50:1 split ratio). The injector temperature was 250°C. The column temperature was initially held at 80°C for 0.5 min and then increased to 180°C at a rate of 10°C/min. The column temperature was subsequently held at 180°C for 15 min and then increased to 220°C at a rate of 4°C/min.

The amount of 2-thiobarbituric acid reactive substances (TBARS) was measured according to the method of Pearson [1976]. The samples were tested by the analytical laboratory, which operates under ISO/IEC17025, at the Food Quality Assurance Service Centre of the Institute of Food Research and Product Development, Kasetsart University, Thailand. The TBARS values were expressed as mg of malonaldehyde equivalents per kg of oil.

Biological properties

The total plate count (TPC) and yeast, mould and coliform counts of the mayonnaise samples were tested by the Central Laboratory at the Halal Science Centre of Chulalongkorn University using the method of Maturin & Peeler [2001]. The TPC and yeast, mould and coliform counts were determined according to Chapters 3, 18 and 4, respectively, of the Bacteriological Analytical Manual [Maturin & Peeler, 2001]. The results of the microbiological analyses were compared to the values recommended by Thai Industrial Standard [TIS, 1997, 1402–2540].

TABLE 1. Fatty acid composition of bulk coconut oil (CNO), bulk rice bran oil (RBO) and CNO: RBO blends at different volume ratios.

Fatty acid	CNO (g/100g)	RBO (g/100g)	CNO:RBO ratio			
			10:90 (g/100g)	20:80 (g/100g)	30:70 (g/100g)	40:60 (g/100g)
Caproic acid (C6:0)	0.64	nd	0.11	0.25	0.33	0.41
Caprylic acid (C8:0)	7.61	nd	1.25	2.76	3.62	4.50
Capric acid (C10:0)	5.93	nd	1.66	2.07	2.67	3.34
Lauric acid (C12:0)	47.07	nd	10.39	15.23	20.14	25.23
Total MCFAs	61.25	0	13.41	20.31	26.76	33.48
Myristic acid (C14:0)	19.19	0.43	4.14	6.03	7.97	9.91
Palmitic acid (C16:0)	9.25	20.67	18.84	16.66	15.49	14.22
Stearic acid (C18:0)	3.14	2.09	2.24	2.27	2.34	2.38
Arachidic acid (C20:0)	0.09	0.79	0.70	0.55	0.49	0.42
Behenic acid (C22:0)	nd	0.23	0.20	0.15	0.13	0.11
Lignoceric acid (C24:0)	nd	0.32	0.24	0.22	0.20	0.17
Palmitoleic acid (C16:1n7)	nd	0.23	0.20	0.17	0.14	0.12
Oleic acid (C18:1n9)	5.91	41.62	34.60	30.05	26.38	22.54
Gadoleic acid (C20:1n11)	0.04	0.47	0.40	0.32	0.28	0.24
Erucic acid (C22:1n9)	nd	0.03	0.02	0.02	0.02	nd
Linoleic acid (C18:2n6)	1.13	32.26	24.29	22.65	19.29	16.00
Alpha-linolenic acid (C18:3n3)	nd	0.86	0.72	0.60	0.51	0.41
Total LCFAs	38.75	100	86.59	79.69	73.24	66.52

MCFAs denotes medium-chain fatty acids; LCFAs denotes long-chain fatty acids; nd denotes not detected (Limit of detection = 0.01 g/100g).

Consumer sensory analysis

Fifty untrained panellists were recruited from a pool of faculty, staff, and students at Chulalongkorn University, Bangkok, Thailand. The panel demographics were 48% men and 52% women. Of the 50 panellists, 52% were 18–24 years old, 38% were 25–54 years old, and 10% were 55+ years old. The participants were asked to rate the colour, flavour, texture and overall acceptance of the mayonnaise using a seven-point hedonic scale.

Storage stabilities of selected o/w mayonnaises

Two formulas were selected based on their physical, chemical, biological and sensory properties for the storage stability study. The two selected mayonnaise formulas were stored at room temperature (30±2°C) for up to 4 weeks. The ESI, colour, firmness, viscosity index, TBARS content and microstructure were analysed every week during the storage period. The TPC and yeast, mould and coliform counts were determined every 2 weeks. In addition, the oil-phase crystallisation temperatures of the selected mayonnaises were measured at the beginning and end of storage. All of the procedures were similar to the ones described previously.

Statistical analysis

The data were arranged in a completely randomised design (CRD). All of the experiments were performed in triplicate. The analysis of variance (ANOVA) method was used to analyse the data, and when the data were significantly different, the mean values were compared using Duncan's new multiple range test (DNMRT) at a 95% significance level. SPSS software version 16.0 was employed to analyse the measured data.

RESULTS AND DISCUSSION

Physical and chemical properties of the bulk RBO oil and CNO:RBO blended oils

The CNO oil contained 61.25% MCFAs and 38.75% LCFAs, whereas RBO consisted of 100% LCFAs. The main MCFA in CNO was lauric acid, and the main LCFAs in RBO were oleic acid (C18:1n9) and linoleic acid (C18:2n6). The amount of MCFAs in the blends increased by ~6.7% for every 10% increase in the CNO content (Table 1).

The colours of edible oils were different due to the pigments in their extracted raw materials. RBO had a transparent yellow colour, whereas CNO was white. For the CNO and RBO blends, an increase in the CNO proportion resulted in an increase in the L* values and decreases in the b* and a* values (Table 2).

The oil-phase crystallisation temperatures of the 0:100, 10:90, 20:80, 30:70 and 40:60 CNO:RBO blends were -12.9, -13.0, -14.6, -6.5 and -5.6°C, respectively. Previously, Smet *et al*. [2010] showed that increasing the unsaturated fatty

TABLE 2. Colour values of bulk rice-bran oil (RBO) and coconut: rice bran oil (CNO: RBO) blends at different volume ratios.

Edible oil (v/v)	L*	a*	b*
Bulk RBO	37.27 ± 0.13^{c}	0.08 ± 0.04^{a}	2.03 ± 0.09^{a}
CNO:RBO (10:90)	37.56 ± 0.09^{b}	0.07 ± 0.02^{a}	1.90 ± 0.09^{b}
CNO:RBO (20:80)	37.70 ± 0.06^{a}	0.10 ± 0.05^{a}	1.80 ± 0.07^{c}
CNO:RBO (30:70)	37.67 ± 0.05^{a}	-0.11 ± 0.05^{b}	1.64 ± 0.09^{d}
CNO:RBO (40:60)	37.69 ± 0.11^{a}	-0.07 ± 0.06^{b}	1.24 ± 0.06^{e}

Values are means ± SD (n=3). Means within a column with different superscripts are significantly different (p≤0.05).

acid content affects the crystallisation behaviour of milk fat by decreasing the onset crystallisation temperature. In this study, the degree of saturation and the oil-phase crystallisation temperature both increased as the proportion of CNO in the blend increased. Tan & Man [2000] studied the thermal behaviours of 17 vegetable oils using DSC and found that the crystallisation temperature increased with increasing degree of saturation in the oils, which is consistent with our results.

Physical, chemical and sensory properties of the freshly prepared mayonnaise

The ESIs of the freshly prepared mayonnaises made with the bulk RBO and oil blends were all 100% (data not shown). All emulsions showed good stability, without gravitational separation after 4 weeks of quiescent storage.

The crystallisation of solid fats in o/w emulsion droplets influences the stability, rheology and appearance of the emulsion. Therefore, it is important to analyse the crystallisation process in o/w emulsions [Rajab, 2014]. In this study, the oil-phase crystallisation temperatures of the freshly prepared mayonnaises made with the bulk RBO and oil blends were determined to be -13.9, -13.9, -17.5, -9.8 and -8.2°C for the 0:100, 10:90, 20:80, 30:70 and 40:60 CNO:RBO blends, respectively. Based on the crystallisation behaviour, the CNO:RBO o/w emulsions were divided into two groups: the first group consisted of emulsions using less than 20% CNO, which had similar oil-phase crystallisation temperatures, and the second group comprised emulsions using 30–40% CNO, which had higher oil-phase crystallisation temperatures. The chemical structure of an oil affects the crystallisation behaviour of its o/w emulsion. The oil phases of the mayonnaises containing mainly unsaturated fatty acids (the first group) had chemical structures similar to that of the bulk RBO oil; therefore, these oil phases and the bulk RBO oil had similar nucleation rates. On the other hand, an increase in the oil-phase MCT content in the mayonnaise led to an increase in the saturated triglycerides as RBO was replaced with CNO. Therefore, the amount of fatty acids with different chemical structures than that of the bulk RBO increased, affecting the crystallisation process (increasing the oil-phase crystallisation temperatures of the second group).

The firmness and viscosity indices of the freshly prepared mayonnaises were shown in Table 3. The firmness and viscosity decreased significantly as the CNO proportion in the blend increased. The viscosity of the oil was affected by the number of carbon atoms in the fatty acid molecules; it increased as the number of carbon atoms in the fatty acid molecules increased [Refaat, 2009]. RBO contains predominantly long-chain fatty acids and therefore has a higher viscosity than CNO, which is mainly composed of medium-chain fatty acids. Noureddini *et al*. [1992] reported that medium-chain fatty acids (nonanoic, capric and lauric acids) have lower viscosities than long-chain fatty acids (myristic, palmitic, stearic, oleic and erucic acids) at the same temperature.

As the CNO proportion in the blend increased, the L* value decreased, whereas the b* value increased ($p<0.05$). The a* values of all of the mayonnaise formulas were not significantly different ($p>0.05$) (Table 3). When the CNO proportion in the formula increased, the mayonnaise viscosity decreased, the oil droplets could flow freely, and the light scattering of the emulsion tended to decrease. Therefore, more light was transmitted, leading to a decrease in the L* value. Although the b* values increased, the increases were small and not perceivable [Sharma, 2003].

The mayonnaise made with 100% rice bran oil (bulk RBO) had a larger average droplet size than those made with the 10–40% coconut oil blends (Figure 1). Although the droplet size decreased with increasing CNO content in the blend, the range of droplet sizes was narrower (data not shown). Hayati *et al*. [2009a] reported that the droplets in an o/w emulsion containing a 30:70 palm kernel olein:soybean oil blend were small and uniform in size, leading to good stability; oil separation was not observed after centrifugation or the addition of carboxymethyl cellulose (CMC).

The oxidative status of the blends as measured by their TBARS values were 0.23, 0.19, 0.30, 0.27 and 0.16 mg malonaldehyde/kg oil for the 0:100, 10:90, 20:80, 30:70 and 40:60 CNO:RBO blends, respectively (Figure 3). These values were very low (<1 mg malonaldehyde/kg oil), well below the value indicating rancidity [Kamel & Sheikh, 2012].

The sensory colour scores did not differ between the samples ($p>0.05$). Only the texture scores of the 20:80 and 40:60 samples were below those of control samples. The flavour scores of the blends were lower than that of the RBO sample. However, the blend samples did not differ in overall acceptance ($p>0.05$) (Table 4). The flavour appears to affect the overall scores the most. For the CNO:RBO 30:70 mayonnaise, the sensory colour evaluation result was not significantly different from those for the other oil-blend mayonnaises ($p>0.05$), but its texture achieved an acceptance similar to that of the RBO mayonnaise, which had the highest overall acceptance score. Moreover, the overall acceptance of the CNO:RBO 30:70 mayonnaise was not significantly different ($p>0.05$) from those of the CNO:RBO 10:90, 20:80 and 40:60 mayonnaises. The acceptance of the CNO:RBO 40:60 mayonnaise flavour was the lowest. Therefore, the CNO:RBO 30:70 and bulk RBO (0:100) mayonnaises were selected for the storage stability study.

Physical and chemical properties of the mayonnaise during storage for 4 weeks

In concentrated emulsions, the droplets tend to flocculate and aggregate into fairly loose, non-spherical, inhomogeneous droplets. After 4 weeks of storage at 30±2°C, some droplets in the bulk RBO mayonnaise coalesced (as shown by the arrow), resulting in an increase in the droplet size (Figure 1). In contrast, some flocculation occurred in the CNO:RBO (30:70) mayonnaise, but the droplet size did not change in comparison to that of the bulk RBO mayonnaise (Figure 2). Triglyceride mixing could also occur by the coalescence of oil droplets or by another physical instability phenomena [Malassagne-Bulgarelli & McGrath, 2009; Raudsepp *et al*., 2014]. Hayati *et al*. [2007] found that the droplet size of emulsions using 100% soybean oil as the oil base changed faster after 30 days of storage than that of emulsions using 10–30% palm

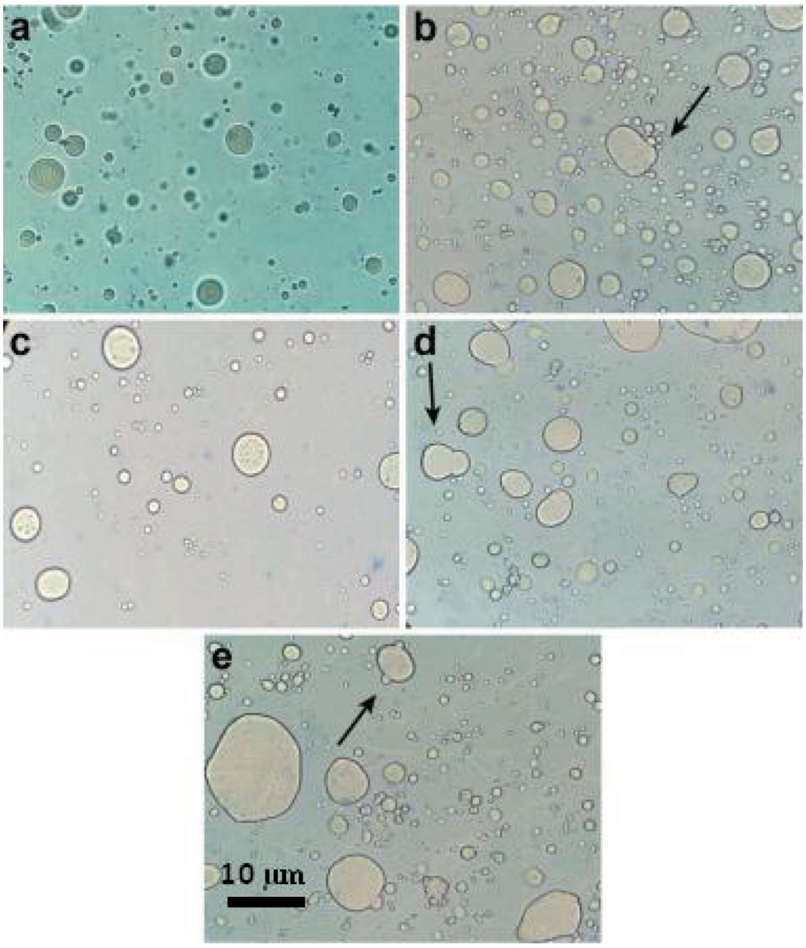

FIGURE 1. Microstructure of bulk RBO mayonnaise: a) fresh, without storage; b, c, d and e) stored in quiescent conditions for 1, 2, 3 and 4 weeks, respectively. Magnification: 40x.

oil as a substitute. Medium-chain fatty acids (6–12 carbon atoms), which are commonly found in coconut and palm kernel oils, are more polar [Galante & Tenore, 2005] than long-chain fatty acids, meaning they are more soluble in the continuous phase, which leads to a decrease in the interfacial tension between the dispersed and continuous phases.

The mayonnaises did not separate during the 4-week storage period; thus, the emulsion stability indices (% ESI) of both mayonnaises (CNO:RBO=0:100 and 30:70) were 100% during storage. This result demonstrated the good stability of the bulk RBO and CNO:RBO 30:70 mayonnaises during a 4-week storage period.

During storage, the L*, a* and b* values of both the RBO and CNO:RBO 30:70 o/w mayonnaises decreased ($p<0.05$) (Table 5). The aggregate sizes in the mayonnaises increased during storage due to the flocculation of some of the oil droplet aggregates, leading to an increase in the light transmission through the mayonnaises. Therefore, the lightness (L*) values decreased.

The firmness and viscosity index of the RBO mayonnaise decreased during storage ($p<0.05$) (Table 5). As the storage time increased, the oil droplets coalesced to give larger droplets. An increase in the droplet size results in a decrease in the number of droplets per unit volume of the emulsion,

TABLE 3. Colour values, firmness and Viscosity Index (g×sec) of fresh-prepared mayonnaises using bulk rice bran oil (RBO) or coconut: rice bran oil (CNO: RBO) blends at different volume ratios.

Edible oil (v/v)	L*	a*	b*	Firmness (g)	Viscosity Index (g×sec)
Bulk RBO	69.54±0.05^{a}	-3.28±0.08^{a}	20.35±0.50^{b}	131.81±10.84^{a}	439.58±3.01^{a}
CNO:RBO (10:90)	69.38±0.08^{a}	-3.30±0.04^{a}	20.17±0.05^{b}	117.31±2.14^{b}	412.60±2.08^{b}
CNO:RBO (20:80)	67.55±0.21^{b}	-3.23±0.05^{a}	20.34±0.13^{b}	123.12±1.34^{ab}	431.13±9.16^{a}
CNO:RBO (30:70)	67.20±0.23^{c}	-3.23±0.08^{a}	20.30±0.08^{b}	97.60±1.05^{c}	335.70±2.34^{c}
CNO:RBO (40:60)	66.15±0.43^{d}	-3.29±0.23^{a}	21.12±0.32^{a}	89.41±2.75^{c}	320.25±9.70^{d}

Values are means ± SD (n=3). Means within a column with different superscripts are significantly different ($p\leq0.05$).

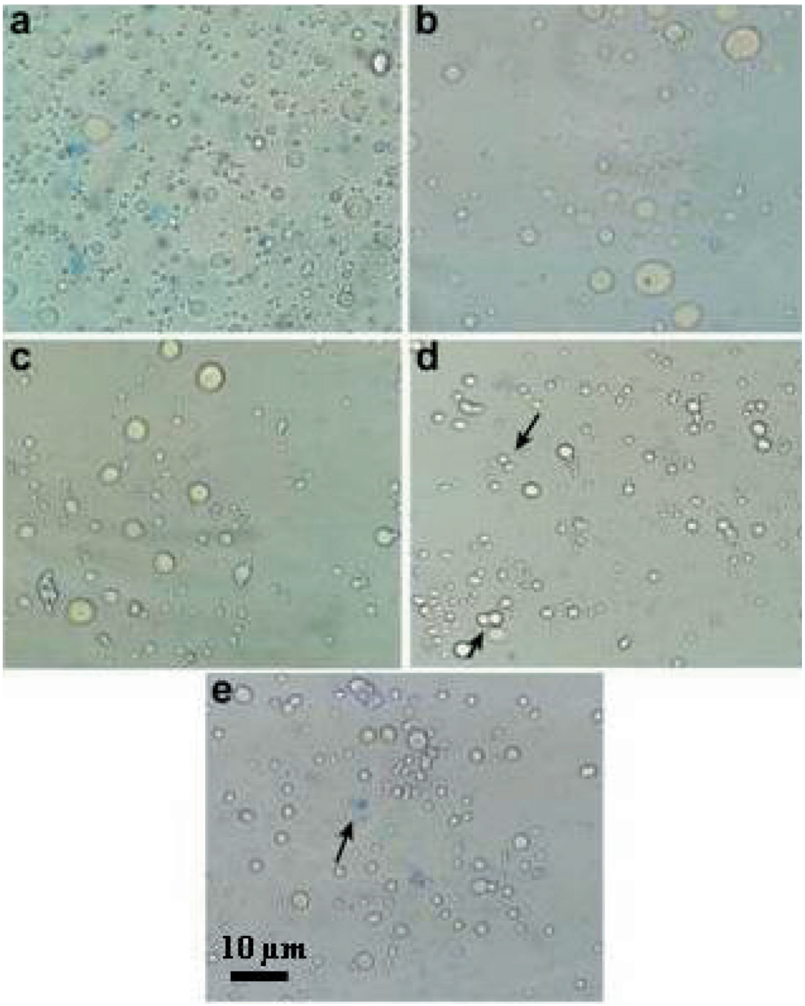

FIGURE 2. Microstructure of CNO:RBO (30:70 v/v) mayonnaise: a) fresh, without storage; b, c, d and e) stored in quiescent conditions for 1, 2, 3 and 4 weeks, respectively. Magnification: 40x.

and thus, the average separation distance between the droplets increases [McClements, 2005]. The droplets become accordingly more mobile and less resistant to flow [Hayati *et al.*, 2007]. In relation to emulsion rheology, the coalescence of oil droplets is normally accompanied by a decrease in the emulsion viscosity [Tadros, 2004].

In contrast, the firmness and viscosity index of the CNO:RBO 30:70 mayonnaise increased ($p<0.05$) during storage (Table 5), due to flocculation of some of the oil droplets. The droplets in concentrated o/w emulsions tend to flocculate due to colloidal and hydrodynamic interactions and to entanglement. Emulsions with flocculated oil droplets have higher viscosities than unflocculated emulsions. The flocculated particles contained the continuous phase in addition to the oil droplets, which resulted in a higher emulsion volume fraction and therefore a higher emulsion viscosity [McClements, 2005].

The oil-phase crystallisation temperatures of the bulk RBO and CNO:RBO 30:70 mayonnaises at the beginning and after 4 weeks of storage did not differ ($p>0.05$). These temperatures

TABLE 4. Sensory evaluation scores of fresh-prepared mayonnaises using bulk rice bran oil (RBO) or coconut: rice bran oil (CNO: RBO) blends at different volume ratios.

Mayonnaise formula	Colour	Texture	Flavour	Overall acceptance
Bulk RBO	4.58 ± 1.13^{a}	4.88 ± 1.10^{a}	5.28 ± 1.28^{a}	5.12 ± 1.15^{a}
CNO:RBO (10:90)	4.92 ± 1.16^{a}	4.70 ± 1.11^{ab}	4.10 ± 1.58^{b}	4.24 ± 1.30^{b}
CNO:RBO (20:80)	4.64 ± 1.19^{a}	4.30 ± 1.22^{b}	3.72 ± 1.37^{bc}	4.10 ± 1.09^{b}
CNO:RBO (30:70)	4.72 ± 1.14^{a}	4.52 ± 0.95^{ab}	4.04 ± 1.31^{b}	4.04 ± 1.31^{b}
CNO:RBO (40:60)	4.76 ± 1.17^{a}	4.30 ± 1.15^{b}	3.42 ± 1.50^{c}	3.78 ± 1.23^{b}

Sensory scores on a 7-point hedonic scale with 4 being the minimum acceptable score. Values are means ± SD (n=3). Means within a column with different superscripts are significantly different ($p\leq0.05$).

TABLE 5. Colour values, firmness and Viscosity Index (g×sec) of RBO mayonnaise and coconut:rice bran oil (CNO:RBO = 30:70) mayonnaise during storage at 30±2°C.

Sample	Attribute	Week 0	Week 1	Week 2	Week 3	Week 4
RBO mayonnaise	L*	66.65±0.04[a]	65.92±0.04[b]	65.89±0.06[b]	65.91±0.06[b]	65.88±0.02[b]
	a*	-1.06±0.02[a]	-1.25±0.02[b]	-1.52±0.03[d]	-1.30±0.03[c]	-1.59±0.04[e]
	b*	19.59±0.15[a]	18.94±0.21[b]	18.71±0.04[c]	18.29±0.22[d]	18.39±0.19[d]
	Firmness (g)	134.82±4.47[a]	127.62±5.98[ab]	133.76±6.44[a]	123.41±3.73[b]	112.44±9.33[c]
	Viscosity index (g×sec)	450.89±17.57[a]	432.89±5.86[ab]	427.11±12.39[bc]	408.76±5.47[cd]	395.34±9.09[d]
Coconut:rice bran oil (CNO:RBO = 30:70) mayonnaise	L*	67.45±0.07[a]	66.96±0.08[b]	66.11±0.03[c]	66.15±0.05[c]	66.14±0.03[c]
	a*	-0.91±0.07[a]	-0.95±0.03[b]	-1.37±0.01[c]	-1.35±0.03[c]	-1.44±0.03[d]
	b*	19.62±0.09[a]	19.27±0.21[b]	18.63±0.10[c]	18.16±0.06[d]	18.15±0.07[d]
	Firmness (g)	106.80±0.81[c]	114.42±3.16[b]	118.44±6.28[ab]	119.77±0.32[ab]	123.69±3.77[a]
	Viscosity index (g×sec)	367.00±0.16[b]	400.57±3.96[a]	398.31±5.31[a]	396.46±8.95[a]	399.78±6.04[a]

Values are means ± SD (n=3). Means within a row with different superscripts are significantly different (p≤0.05).

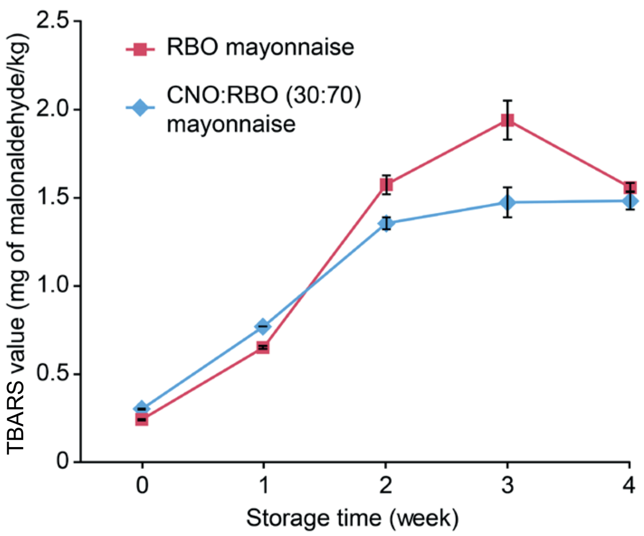

FIGURE 3. TBARS values of rice bran (RBO) and coconut/rice bran (CNO:RBO=30:70) mayonnaise during storage at 30 ± 2°C (Values are the mean of three independent determinations (n=3) and SD is represented by the error bars).

were -13.6 and -13.2°C for the RBO mayonnaise before and after storage, respectively, and -9.7 and -9.5°C for the CNO:RBO 30:70 mayonnaise before and after storage, respectively. Thus, the thermal behaviours of the two mayonnaise formulas did not change significantly during the storage period.

The TBARS content of the bulk RBO (CNO:RBO 0:100) was higher than that of the fresh CNO:RBO 30:70 sample (Figure 3) because the bulk RBO contains more unsaturated fatty acids (Table 1), which are more likely to be oxidised. However, for the first seven days of storage, the TBARS content of the bulk RBO mayonnaise was lower than that of the CNO:RBO 30:70 mayonnaise (Figure 3). Rice bran oil contains oryzanol, tocopherols and tocotrienols [Ghosh, 2007; Gunstone, 2011], which helped to reduce the initial oxidation of the mayonnaise. The TBARS content of the bulk RBO mayonnaise increased up to day 21 and then decreased after that. This apparent decrease might have occurred because malonaldehyde might react with the protein amino groups, resulting in a lower TBARS content [Damodaran, 2008; McClements & Decker, 2008]. The MCT oil might have inhibited the oxidation of the o/w mayonnaise because unsaturated triglycerides were replaced by the MCTs at the droplet surface, resulting in a surface covered with non--oxidisable triglycerides. The MCT-covered surface could form an insulating layer between the radicals in the aqueous phase and the oil droplets (unsaturated triglycerides), efficiently preventing the initiation of lipid oxidation [Raudsepp *et al*., 2014].

After 4 weeks of storage, the total plate, yeast, mould and coliform counts of the bulk RBO and CNO:RBO 30:70 mayonnaises were below the recommended values of the Thai Industrial Standard [1997] (total plate count <1000 CFU/g, yeast and mould counts <10 CFU/g and coliform count <3 MPN/g). Therefore, both mayonnaises exhibited good microbiological stability during the 4-week storage period.

CONCLUSIONS

A significant replacement of RBO with CNO in o/w emulsions affected the physical, chemical and sensory properties. In this study, the highest replacement of RBO with CNO in an o/w emulsion that could be achieved with minimal negative effect was 30%. This level of replacement did not affect ESI, droplet size or uniformity during 4 weeks of storage. In addition, after 4 weeks of storage, the crystallisation temperature of the 30% replacement was less changed from the beginning day, and its microbial properties showed good stability. The results from this study provide potential applications of coconut and rice-bran oil blends and useful information for partial replacement of long-chain fatty acids with medium-chain fatty acids in o/w emulsion preparations.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest.

REFERENCES

1. Abteilung M., München-Schwabing K., Changes in ultrasonic findings in the liver in relation to parenteral nutrition with long chain triglyceride and medium chain triglyceride/long chain triglyceride lipid solutions. Inf. Ther., 1988,15, 140–143.
2. Alexandrou E., Herzberg G.R., White M.D., High-level medium--chain triglyceride feeding and energy expenditure in normal--weight women. Can. J. Physiol. Pharmacol., 2007, 85, 507–513.
3. Clegg M.E., Medium-chain triglycerides are advantageous in promoting weight loss although not beneficial to exercise performance. Int. J. Food Sci. Nutr., 2010, 61, 653–679.
4. Damodaran S., Amino acids, peptides and proteins. 2008, *in:* Fennema's Food Chemistry (eds. S. Damodaran, K.L. Parkin, O.R. Fennema). CRC Press, Boca Raton, pp. 219–323.
5. De Vogel-van den Bosch J., Hoeks J., Timmers S., Houten S.M., van Dijk P.J., Boon W., Van Beurden D., Schaart G., Kersten S., Voshol P.J., The effects of long- or medium-chain fat diets on glucose tolerance and myocellular content of lipid intermediates in rats. Obesity, 2011a, 19, 792–799.
6. De Vogel-van den Bosch J., van den Berg S.A., Bijland S., Voshol P.J., Havekes L.M, Romijn H.A., Hoeks J, van Beurden D, Hesselink M.K., Schrauwen P., vanDijk K.W., High-fat diets rich in medium- versus long-chain fatty acids induce distinct patterns of tissue specific insulin resistance. J. Nutr. Biochem., 2011b, 22, 366–371.
7. Galante J.H., Tenore R.R., Medium-chain triglycerides. 2005, *in*: Handbook of Functional Lipids (ed. C.C. Akoh). CRC Press Inc., Boca Raton, Florida, pp. 177–183.
8. Ghosh M., Review on recent trends in rice bran oil processing. J. Amer. Oil Chem. Soc., 2007, 84, 315–324.
9. Gunstone F.D., Vegetable Oils in Food Technology: Composition, Properties and Uses, 2nd edn., 2011, Blackwell Publishing, Oxford, pp.20–21, 159–160.
10. Han J., Hamilton J.A., Kirkland J.L., Corkey B.F., Guo W., Medium-chain oil reduces fat mass and down-regulates expression of adipogenic genes in rats. Obes. Res., 2003, 11, 734–744.
11. Hayati I.N., Man Y.B.C., Tan C.P., Aini I.N., Stability and rheology of concentrated o/w emulsions based on soybean oil/palm kernel olein blends. Food Res. Int., 2007, 40, 1051–1061.
12. Hayati I.N., Man Y.B.C., Tan C.P., Aini I.N., Droplet characterization and stability of soybean oil/palm kernel olein o/w emulsions with the presence of selected polysaccharides. Food Hydrocolloid., 2009a, 23, 233–243.
13. Hayati I.N., Man Y.B.C., Tan C.P., Aini I.N., Thermal behaviour of concentrated oil-in-water emulsions based on soybean oil and palm kernel olein blends. Food Res. Int., 2009b, 42, 1223–1232.
14. Kamel S.M., Sheikh E., Quality evaluation of some commercially fried fast Food. Food Sci. Qual. Manag., 2012, 10, 29–36.
15. Lepage G., Roy C.C., Direct transesterification of all classes of lipids in a one-step reaction. J. Lipid Res., 1986, 27, 114–120.
16. Liu H., Xu X.M., Guo S.D., Rheological, texture and sensory properties of low-fat mayonnaise with different fat mimetics. LWT – Food Sci., Technol., 2007, 40, 946–954.
17. Ma C.J., Wu J.M., Tsai H.L., Huang C.W., Lu C.Y., Sun L.C., Shih Y.L., Chen C.W., Chuang J.F., Wu M.H., Wang M.Y., Lin M.T., Wang J.Y., Prospective double-blind randomized study on the efficacy and safety of an n-3 fatty acid enriched intravenous fat emulsion in postsurgical gastric and colorectal cancer patients. Nutr. J., 2015, 14, 9.
18. Malassagne-Bulgarelli N., McGrath K.M., Dynamics of oil transfer in oil-in-water emulsions. Soft Matter., 2009, 5, 4804––4813.
19. Marten B., Pfeuffer M., Schrezenmeir J., Medium-chain triglycerides. Int. Dairy J., 2006, 16, 1374–1382.
20. Matulka R.A., Noguchi O., Nosaka N., Safety evaluation of a medium- and long-chain triacylglycerol oil produced from medium-chain triacylglycerols and edible vegetable oil. Food Chem. Toxicol., 2006, 44, 1530–1538.
21. Maturin L.J., Peeler J.T., Bacteriological Analytical Manual 2001 [online]. Available at: [http://www.fda.gov/Food/ScienceResearch/LaboratoryMethods/BacteriologicalAnalyticalManualBA/UCM063346].
22. McClements D.J., Food Emulsions: Principles, Practices and Techniques. 2005, 2nd edn. CRC Press Inc., Boca Raton, New York, pp. 382–385.
23. McClements D.J., Decker E.A., Lipids. 2008, *in:* Fennema's Food Chemistry (eds. S. Damodaran, K.L. Parkin, O.R. Fennema). CRC Press Inc., Boca Raton, Florida, pp. 156–182,
24. Mirhosseini H., Tan C.P., Hamid N.S.A., Yusof S., Effect of Arabic gum, xanthan gum and orange oil content on ζ- potential, conductivity, stability, size index and pH of orange beverage emulsion. Colloids Surf. A: Physiochem. Eng. Asp., 2008, 315, 47–56.
25. Montgomery M.K., Osborne B., Brown S.H., Small L., Mitchell T.W., Cooney G.J., Turner N.J., Contrasting metabolic effects of medium- versus long-chain fatty acids in skeletal muscle. J. Lipid Res., 2013, 54, 3322–3333.
26. Mumme K., Stonehouse W., Effects of medium-chain triglycerides on weight loss and body composition: a meta-analysis of randomized controlled trials. J. Acad. Nutr. Diet., 2015, 115, 249–263.
27. Nagao K., Yanagita T., Medium-chain fatty acids: functional lipids for the prevention and treatment of the metabolic syndrome. Pharmacol. Res., 2010, 61, 208–212.
28. Nasaka N., Kasai M., Nagamura M., Tagahashi I., Itakura M., Takeuchi H., Aoyama T., Tsuji H., Okasaki M., Kondo K., Effect of dietary medium-chain triglycerides on serum lipoproteins and biochemical parameters in healthy men. Biosci. Biotechnol. Biochem., 2002, 66, 1713–1718.
29. Noureddini H., Teoh B.C., Clements L.D., Viscosities of vegetable oils and fatty acids. J. Amer. Oil Chem. Soc., 1992, 69, 1189–1191.

30. Pearson D., The Chemical Analysis of Foods. 1976. 7th edn, Chapter 14, SheckWah Tong Printing Press Inc., Hong Kong, pp. 488–518.
31. Rajab K.K., Fats in Food Technology. 2014. 2nd edn, Chapter 4, Wiley Blackwell, Oxford, pp. 153–155.
32. Raudsepp P., Brüggemann D.A., Lenferink A., Otto C., Andersen M.L., Oxidative stabilization of mixed mayonnaises made with linseed oil and saturated medium-chain triglyceride oil. Food Chem., 2014, 152, 378–385.
33. Refaat A.A., Correlation between the chemical structure of biodiesel and its physical properties. Int. J. Environ. Sci. Technol., 2009, 6, 677–694.
34. Ruan W., French D., Wong A., Drasner K, Wu A.H., A mixed (long- and medium-chain) triglyceride lipid emulsion extracts local anesthetic from human serum *in vitro* more effectively than a long-chain emulsion. Anesthesiology, 2012, 116, 334–339.
35. Sharma G., Digital Color Imaging Handbook. 2003, Chapter 1, CRC Press LLC, Boca Raton, Florida, pp. 31–32.
36. Smet K., Coudijzer K., Fredrick E., DeCampeneer E.S., De Block J., Wouters J., Raes K., Dewettinck K., Crystallization behaviour of milk fat obtained from linseed-fed cows. J. Dairy Sci., 2010, 93, 495–505.
37. St-Onge M.P., Bosarge A., Weight-loss diet that includes consumption of medium-chain triacylglycerol oil leads to a greater rate of weight and fat mass loss than does olive oil. Am. J. Clin. Nutr., 2008, 87, 621–626.
38. St-Onge M.P., Ross P.R., Parson W.D., Jones P.J.H., Medium--chain triglycerides increase energy expenditure and decrease adiposity in overweight men. Obes. Res., 2003, 11, 395–402.
39. Tadros T., Application of rheology for assessment and prediction of the long-term physical stability of emulsions. Adv. Colloid Inter. Sci., 2004, 108–109, 227–258.
40. Tan C.P., Man Y.B.C., Differential scanning calorimetric analysis of edible oils: comparison of thermal properties and chemical composition. J. Amer. Oil Chem. Soc., 2000, 77, 143–155.
41. Thai Industrial Standard (1402–2540), Mayonnaise and Salad Cream 1997 [online]. Available at: [http://www2.rid.go.th/research/vijais/moa/fulltext/TIS1402–2540.pdf].
42. Trevizan L., de Mello Kessler A., Bigley K.E., Anderson W.H., Waldron M.K., Bauer J.E., Effects of dietary medium-chain triglycerides on plasma lipids and lipoprotein distribution and food aversion in cats. Am. J. Vet. Res., 2010, 71, 435–440.
43. Wein S., Wolffram S., Schrezenmeir J., Gasperiková D., Klimes I., Seböková E., Medium-chain fatty acids ameliorate insulin resistance caused by high-fat diets in rats. Diabetes Metab. Res. Rev., 2009, 25, 185–194.
44. Wycherley T.P., Moran L.J., Clifton P.M., Noakes M., Brinkworth G.D., Effects of energy-restricted high-protein, low-fat compared with standard-protein, low-fat diets: a meta-analysis of randomized controlled trials. Am. J. Clin. Nutr., 2012, 96, 1281–1298.

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