International Food Research Journal 18: 355-366 (2011)

The use of enzymatically synthesized medium– and long-chain triacylglycerols (MLCT) oil blends in food application

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Abstract: The potential use of medium- and long-chain triacylglycerols (MLCT) oil blends in food applications such as frying oil and salad dressings were investigated. The frying strength of palm-based MLCT oil with different antioxidants under deep frying conditions was assessed. Palm-based MLCT oil showed better thermal-resistant oxidative strength than refined, bleached and deodorized (RBD) palm olein throughout the five consecutive days of frying. Sensory evaluation and rancidity assessment on fried chips showed no significant differences ($P > 0.05$) between chips fried in RBD palm olein and palm-based MLCT oil. MLCT-based salad dressings treated with different antioxidants showed similar rheological behaviors as compared to soybean-based salad dressings. The overall quality of the physical appearance and organoleptic acceptability based on quantitative descriptive analysis showed no significant differences (P > 0.05) in all salad dressings. These findings indicated that MLCT-based oil blends can be used as healthy functional oil for daily consumption.

Keywords: frying oil, salad dressing, medium- and long-chain triacylglycerols (MLCT), antioxidant, rheological behavior

Introduction

Medium- and long-chain triacylglycerols (MLCT) are the latest structured lipids being focused nowadays, composed of mainly medium-chain fatty acids (MCFA, C_6 - C_{10}) and long-chain fatty acids (LCFA, C_{12} - C_{24}) in the same triacylglycerol. Most of the MLCT works were designed to provide the health benefits fatty acids for nutritive purposes, targeting specific disease and metabolic conditions (Rubin et al. 2000; Kim and Akoh, 2005; Mu and Porsgaard, 2005; Matulka et al. 2006). A number of published papers proven that MLCT diet has lower fat accumulation as opposed to other oils and the main reasons are due to the enhancement of energy expenditure and medium-chain fatty acids oxidation without activating *de novo* lipogenesis (Bendixen et al. 2002; Kasai et al. 2003; Matsuo and Takeuchi, 2004; Shinohara et al. 2002 & 2005). Both clinical tests on animals and humans showed that MLCT was effective to decrease the accumulation of body fat and was suitable for long-term dietary therapy (Matsuo et al., 2001; Matsuo and Takeuchi, 2004). Compared to physical mixtures of medium-chain triacylglycerols and long-chain triacylglycerols, MLCT has better cooking properties as it has higher smoke point and less foaming tendency (Matsuo et al. 2001; Negishi et al. 2003).

Current known MLCT was produced either using lipase or chemical catalysts via transesterification or acidolysis processes. The most commonly used method for the MLCT production is acidolysis, using a regiospecific lipase to incorporate the MCFA into the triacylglycerols (Fomuso and Akoh 1997; Mu et al. 2001; Kawashima et al. 2004; Kim and Akoh, 2005). To our knowledge, there is no reported work on the production of concentrated MLCT oil using lipase-catalyzed esterification. In this study, the synthesis of MLCT oil from a mixtures of oleic and capric acid, and glycerol using Lipozyme RM 1M lipase was carried out with the aims of producing concentrated MLCT oil that will be blended with other oils to be used as anti-obesity cooking oil and salad dressings

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applications. The lipase-catalyzed esterification of MLCT oil was produced using optimal parameters obtained from the mathematic modeling of response surface methodology as determined in our previous study (Koh et al., 2010). This paper was focused on the deep frying performance and rheological behaviors study of the enzymatically synthesized MLCT oil blended with palm olein and soybean oil, respectively. The main objective was to investigate the frying strength of palm-based MLCT oil and visco-elastic properties of MLCT-based dressing. Sensory analysis on fried chips and MLCT-based dressings also carried out to determine the organoleptic acceptability of MLCT oil in food applications using trained panelists.

Materials and Methods

Materials

Immobilised lipase from *Rhizomucor meihei* (Lipozyme RM IM) was purchased from Novozymes A/S. Capric acid (99.9%), glycerol (99.8%) and concentrated oleic acid (purity >75%, w/w) was purchased from Cognis Oleochemicals (M) Sdn. Bhd. A commercial sage (Herbalox seasoning, Type S-O) extracts and Tert-butylhydroquinone, TBHQ were used as natural and synthetic antioxidants, respectively.

Preparation of concentrated MLCT oil

The concentrated MLCT oil was produced through esterification synthesis of capric, oleic acid and glycerol via Lipozyme RM IM lipase, using the optimum parameter determined in our previous study (Koh et al. 2009; 2010). The MLCT oil was produced using 16 L packed-bed bioreactor, conducted at 70°C for 14 h with 10% (w/w) enzyme packed in a column under vacuum conditions to remove excess water. The crude MLCT oil was deodorized using a 2 kg laboratory-scale deodorizer to remove free fatty acid and monoacylglycerols, and the final oil was decolorized using a 500 mL film evaporator and short-path distillator. The running conditions for short path distillation were as follows: evaporator vacuum 0.006mbar; condenser temperature 40°C; evaporator temperature 260°C; feed temperature 55°C; roller speed rate 350 rpm with flow rate of approximately 1.5 mL/min.

Frying experiment

The frying experiments were conducted in three oil systems: a) RBD palm olein (System A); b) Palm-based MLCT oil with 200 ppm TBHQ (System B); c) Palm-based MLCT oil with 1000 ppm oleoresin sage extracts (System C). A batch of 100 g of raw potato slice was fried for 3 min for a period of 3.5 h per day with 10 batches of fries per day. A total of 50 frying batches for five consecutive frying days were conducted. Potato chips collected from the first to ninth batches of the first day of frying were kept at ambient temperature for sensory evaluation and rancidity assessment.

Preparation of salad dressings

Oil-in-water emulsions (50%, v/v) were prepared for three types of salad dressings, using a Silverson L4RT shear mixer (Silverson Machines Limited, Bucks, UK) equipped with a square hole high-shear screen that provides fine droplet size. Soybean oil, commonly used in the salad dressings preparation, was used as control and denoted as System I. Two types of antioxidants, 200 ppm TBHQ and 1000 ppm oleoresin sage extracts were added separately to the MLCT oil blends and denoted as System II and III, respectively. The ingredients used to prepare salad dressings include 1% (w/v) gum Arabic, 0.5% (w/v) xantham gum, lemon juice, 0.1% (w/v) sodium benzoate, 1.5% (w/v) salt, 6% (w/v) sugar and 2.5% (w/v) egg yolk.

Analyses of oil

Free fatty acid content (Ca 5a-40), iodine value (Cd 1d-92), smoke point (Cc 9a-48), peroxide value (Cd 8-53) and anisidine value (Cd 18-90) were determined using AOCS Official Methods. The oil color (PORIM p4.1, 1995) was measured in 5 1/4-inch cell in a Lovibond Tintometer (Salibury, UK). The primary and secondary products of oxidation were analyzed through spectrophotometric measurement at the wavelength of 232 and 268 nm, respectively using IUPAC 2.505 methods. Food oil sensor was used to determine total polar compounds of fried oil (Stier, 2004). The rancimat induction period of oil was determined with a 743 Rancimat Apparatus (Metrohm, Switzerland), whereby 3 g oil was heated to 120°C under an air flow rate of 20 L/ h. The fatty acid analysis was performed by converting the free and glyceride fatty acid to their corresponding methyl esters prior to the analysis by gas chromatography (PORIM 1995, p. 3.4). The triacylglycerols structured of refined MLCT oil was analyzed using HPLC method. The sample was prepared by dissolving a liquid fraction of 10% of the analyte in appropriate amount of acetone. The products were analyzed using an SCL-10A HPLC (Shimadzu, Kyoto, Japan) equipped with a Sil-10AD auto-injector (Shimadzu) and RID-10A refractive index detector (Shimadzu). A precoated silica reversed-phase C18 HPLC column, LiChroCART® 5µm (4 mm x 25 cm) from Merck (Darmstadt, Germany) was used as a stationary phase. The column temperature was set at 40°C. The isocratic mobile phase consisted of acetone and acetonitrile (50:50) with a flow rate of 1 mL/min. Peak identification was performed by determining the range of retention times at which the relevant compounds elute, using selected reference standards.

Rheological analysis

Visco-elastic properties of salad dressings were analyzed using a Dynamic Controlled Stress Rheometer (Model RS600, Thermo Electron Corporation, Karlsruhe, Germany). The parallel-plate geometry was used, with a diameter of 35 mm and a gap of 1 mm. A dynamic stress sweep was carried out on all dressing samples, with the range varying from 0.1 to 500 Pa, the frequency maintained at 1 Hz and the temperature controlled at 4°C. To study the time-dependent thixotrophy behavior of salad dressings, a flow curve was measured and ramped up-time and ramped down-time were used. The thixotrophy value was indicated by the "hysteresis loop" between the up- and down-curves of a flow curve.

Droplet size measurement

The droplet size distribution of the salad dressings was measured using a halogen light-scattering microscope (Axiovert 200; Zeiss GmbH, Germany) equipped with a camera (Axio-Cam MRc; Zeiss GmbH, Germany). Measurements were reported as full particle size distribution based on bound width using software provided by the manufacturer (Axiovision Release 4.5). The emulsion was applied to the microscope slide of the instrument. Each sample was analyzed four times and the data on droplet sizes of emulsion are presented as means.

Product evaluation

A nine-point hedonic scale (1 = like extremely to 9 = dislike extremely) with 40 consumer-type panels were used to evaluate the acceptability of potato chips. An odor perception scoring-point system (Evaluation scale: 1 = very good to 6 = very rancid) was selected to determine the stored potato chips rancid score during storage at ambient temperature for a period of 3 months. Table 1 summarized the descriptive quality ratings of each attribute for salad dressings sensory evaluation. A total of ten trained panelists from the Malaysian Palm Oil Board (MPOB) sensory laboratory were asked to evaluate three types of dressings on the basis of color, odor intensity, taste, viscosity, texture, oiliness, off-flavor and overall quality.

Results and Discussion

In this study, MLCT oil with high concentration of MLCT-type triacylglycerols was prepared based on the optimal parameters obtained from the response surface methodology comprising central composite rotatable design (Koh et al., 2010). The refined MLCT oil was found to contain 76% MLCT-type triacylglycerols after refining by short path distillation. Table 2 summarized the physical and chemical characteristics of refined MLCT oil. The lighter color and low free fatty acid content of MLCT oil with the smoke point value above 180°C indicated that this oil was suitable for frying applications. The triacylglycerols profile of concentrated MLCT oil, which was divided into four different groups, namely as partial acylglycerols, medium-medium-medium-chain triacylglycerols (MMM), medium and long-chain triacylglycerols (MLCT) and long-long-long-chain triacylglycerols (LLL). The MMM yield was kept at a very low level as MMM has a high foaming tendency and lower smoke point. A relative low rancimat hour in refined MLCT oil was observed, mainly due to lack of antioxidants in this MLCT oil. Addition of natural or synthetic antioxidants was crucial to bring up the anti-oxidative strength of MLCT oil blends against thermal oxidation (Koh et al., 2009). The refined MLCT oil was blended with either palm olein or soybean to have at least 12% MCFA in palm or soybean-based MLCT oil blends as Kasai's study (2003) showed that 12% MCFA in MLCT was sufficient to accelerate lipid metabolism.

The frying experiments were conducted at relatively stressed condition with the oil turnover rate of 30.1 h and low ratio of oil to potato chips (2.2 : 1) to shorten the frying days. It is a useful accelerated frying test to examine the frying strength of oil against high thermal oxidation threats in a short period of time (Che Man and Tan, 1999). Under continuous stressed frying condition, palm-based MLCT oil in the presence of synthetic or natural antioxidants showed better thermal-resistant oxidative strength than refined, bleached and deodorized (RBD) palm olein throughout the five consecutive days of frying as shown in Table 3. In summary, rancimat induction period, free fatty acid content, anisidine value, $E^{1\%}_{1cm}$ at 232 and 268nm can be used as oil quality parameters to indicate the degree of oil deterioration against frying periods. No significant changes ($P > 0.05$) in the saturated fatty acids/unsaturated fatty acids (SFA/USFA) ratio cross frying days indicated good thermal oxidative stability of palm-based MLCT oil. Palm-based MLCT oils have inherently higher levels of polar compounds, mainly due to the polarity

Table 1. Descriptive scale of each attribute in quantitative descriptive analysis (QDA) study

Sensory attribute	Vocabulary description scale (ranging from 1 to 9)
Color	Light to dark
Odor intensity	Absent to strong
Taste	Bad to excellent
Viscosity	Very thin to very thick
Texture	Smoothness to grainy
Oiliness	Absent to very oily
Off-flavor	Bad to excellent
Overall quality	Bad to excellent

Table 2. Physical and chemical characteristics of refined MLCT oil[a]

Oil characteristic	Value
Color	0.5R 5Y±0.00
Free fatty acid content	0.020±0.02
Iodine value	59.49±0.28
Smoke point (°C)	210±0.00
Rancimat at 120°C (h)	1.20±0.06
Fatty acid composition (%)	
Medium-chain fatty acids	29.78±0.11
Saturated fatty acids	34.78±0.21
Monounsaturated fatty acids	57.45±0.18
Polyunsaturated fatty acids	7.79±0.01
Triacylglycerols structured (%)	
Partial acylglycerols	10.08±0.1
Medium-medium-medium-chain triacylglycerols (MMM)	3.90±0.1
Medium- and long-chain triacylglycerols (MLCT)	76.82±0.4
Long-long-long-chain triacylglycerols (LLL)	10.22±0.1

[a]Each value in the table represents the mean ± standard deviation from triplicate analyses

Table 3. Changes in rancimat induction period, free fatty acid, peroxide value, anisidine value, $E^{1\%}_{1\,cm}$ at 232 and 268 nm, total polar compounds and ratio of SFA/USFA of different oil systems during frying[a]

Characteristic	Day	System A	System B	System C
Rancimat induction period (h)	0	$13.14 \pm 0.06^{a}_{B}$	$20.65 \pm 0.37^{a}_{A}$	$13.44 \pm 0.66^{a}_{B}$
	1	$6.39 \pm 0.20^{b}_{B}$	$10.54 \pm 0.29^{b}_{A}$	$10.17 \pm 0.50^{b}_{A}$
	2	$3.82 \pm 0.47^{c}_{B}$	$8.70 \pm 0.02^{c}_{A}$	$8.25 \pm 0.21^{c}_{A}$
	3	$2.76 \pm 0.03^{d}_{B}$	$7.17 \pm 0.33^{d}_{A}$	$6.68 \pm 0.15^{d}_{A}$
	4	$0.96 \pm 0.04^{e}_{C}$	$7.03 \pm 0.08^{d}_{A}$	$5.56 \pm 0.12^{e}_{B}$
	5	$0.90 \pm 0.04^{e}_{C}$	$6.63 \pm 0.30^{d}_{A}$	$5.24 \pm 0.07^{e}_{B}$
Free fatty acid (given as % Palmitic acid)	0	$0.04 \pm 0.00^{f}_{B}$	$0.04 \pm 0.00^{e}_{B}$	$0.05 \pm 0.00^{f}_{A}$
	1	$0.11 \pm 0.00^{e}_{A}$	$0.08 \pm 0.00^{d}_{B}$	$0.11 \pm 0.00^{e}_{A}$
	2	$0.19 \pm 0.00^{d}_{A}$	$0.15 \pm 0.02^{c}_{B}$	$0.16 \pm 0.00^{d}_{A}$
	3	$0.27 \pm 0.00^{c}_{A}$	$0.18 \pm 0.02^{c}_{B}$	$0.26 \pm 0.00^{c}_{A}$
	4	$0.34 \pm 0.02^{b}_{A}$	$0.26 \pm 0.02^{b}_{B}$	$0.30 \pm 0.00^{b}_{A,B}$
	5	$0.43 \pm 0.01^{a}_{A}$	$0.32 \pm 0.02^{a}_{C}$	$0.38 \pm 0.01^{a}_{B}$
Peroxide value (meq hydroperoxide/kg oil)	0	$1.64 \pm 0.01^{e}_{C}$	$1.82 \pm 0.01^{c}_{B}$	$1.97 \pm 0.01^{d}_{A}$
	1	$8.67 \pm 0.01^{b}_{A}$	$2.98 \pm 0.03^{b}_{B}$	$2.81 \pm 0.02^{c}_{C}$
	2	$5.17 \pm 0.09^{d}_{A}$	$1.82 \pm 0.02^{c}_{B}$	$1.60 \pm 0.05^{e}_{C}$
	3	$7.55 \pm 0.33^{c}_{A}$	$2.91 \pm 0.34^{b}_{B}$	$3.12 \pm 0.22^{b}_{B}$
	4	$10.66 \pm 0.09^{a}_{A}$	$3.51 \pm 0.22^{a}_{B}$	$3.80 \pm 0.05^{a}_{B}$
	5	$8.43 \pm 0.22^{b}_{A}$	$3.42 \pm 0.11^{a}_{B}$	$3.81 \pm 0.04^{a}_{B}$
Anisidine value	0	$1.41 \pm 0.05^{f}_{C}$	$3.85 \pm 0.05^{f}_{B}$	$4.57 \pm 0.12^{f}_{A}$
	1	$43.87 \pm 0.47^{e}_{A}$	$14.70 \pm 0.25^{e}_{C}$	$15.92 \pm 0.14^{e}_{B}$
	2	$62.88 \pm 0.11^{d}_{A}$	$22.54 \pm 0.17^{d}_{C}$	$24.10 \pm 0.23^{d}_{B}$
	3	$75.37 \pm 0.64^{c}_{A}$	$28.39 \pm 0.03^{c}_{C}$	$30.35 \pm 0.01^{c}_{B}$
	4	$87.02 \pm 0.53^{b}_{A}$	$32.18 \pm 0.35^{b}_{C}$	$34.04 \pm 0.39^{b}_{B}$
	5	$92.34 \pm 0.08^{a}_{A}$	$34.99 \pm 0.39^{a}_{C}$	$36.83 \pm 0.39^{a}_{B}$
$E^{1\%}_{1\,cm}$ at 232 nm	0	$1.76 \pm 0.01^{f}_{C}$	$2.99 \pm 0.04^{f}_{B}$	$3.14 \pm 0.00^{f}_{A}$
	1	$3.91 \pm 0.00^{e}_{A}$	$3.44 \pm 0.00^{e}_{B}$	$3.31 \pm 0.00^{e}_{C}$
	2	$5.14 \pm 0.00^{d}_{A}$	$3.91 \pm 0.01^{d}_{C}$	$4.50 \pm 0.00^{d}_{B}$
	3	$6.14 \pm 0.00^{c}_{A}$	$4.60 \pm 0.00^{c}_{C}$	$4.98 \pm 0.02^{c}_{B}$
	4	$7.83 \pm 0.00^{b}_{A}$	$5.03 \pm 0.00^{b}_{C}$	$5.83 \pm 0.00^{b}_{B}$
	5	$7.89 \pm 0.01^{a}_{A}$	$5.09 \pm 0.01^{a}_{C}$	$6.02 \pm 0.00^{a}_{B}$
$E^{1\%}_{1\,cm}$ at 268 nm	0	$0.46 \pm 0.01^{f}_{C}$	$0.79 \pm 0.00^{e}_{B}$	$0.86 \pm 0.00^{f}_{A}$
	1	$2.23 \pm 0.01^{e}_{A}$	$1.15 \pm 0.00^{d}_{C}$	$1.25 \pm 0.01^{e}_{B}$
	2	$2.79 \pm 0.00^{d}_{A}$	$1.42 \pm 0.00^{c}_{C}$	$1.78 \pm 0.00^{d}_{B}$
	3	$2.96 \pm 0.00^{c}_{A}$	$1.75 \pm 0.00^{b}_{C}$	$2.02 \pm 0.00^{c}_{B}$
	4	$3.10 \pm 0.00^{b}_{A}$	$1.94 \pm 0.00^{a}_{C}$	$2.36 \pm 0.01^{b}_{B}$
	5	$3.14 \pm 0.01^{a}_{A}$	$1.94 \pm 0.01^{a}_{C}$	$2.44 \pm 0.00^{a}_{B}$
Total polar compounds (%)	0	$8.00 \pm 0.00^{f}_{B}$	$18.50 \pm 0.71^{f}_{A}$	$18.00 \pm 0.00^{d}_{A}$
	1	$16.50 \pm 0.71^{e}_{B}$	$25.00 \pm 0.00^{e}_{A}$	$26.50 \pm 0.71^{c}_{A}$
	2	$22.00 \pm 0.00^{d}_{C}$	$29.00 \pm 0.00^{d}_{B}$	$30.00 \pm 0.00^{b}_{A}$
	3	$24.50 \pm 0.71^{c}_{B}$	$30.50 \pm 0.71^{c}_{A}$	$31.00 \pm 0.00^{b}_{A}$
	4	$26.00 \pm 0.00^{b}_{B}$	$32.50 \pm 0.71^{b}_{A}$	$33.50 \pm 0.71^{a}_{A}$
	5	$28.00 \pm 0.00^{a}_{B}$	$34.00 \pm 0.00^{a}_{A}$	$34.50 \pm 0.71^{a}_{A}$
SFA/USFA ratio	0	$0.73 \pm 0.00^{d}_{A}$	$0.59 \pm 0.00^{a}_{B}$	$0.59 \pm 0.01^{a}_{B}$
	1	$0.74 \pm 0.01^{d}_{A}$	$0.57 \pm 0.03^{a,b}_{B}$	$0.57 \pm 0.03^{a,b}_{B}$
	2	$0.74 \pm 0.00^{d}_{A}$	$0.54 \pm 0.00^{b}_{B}$	$0.54 \pm 0.00^{b}_{B}$
	3	$0.75 \pm 0.00^{c}_{A}$	$0.55 \pm 0.01^{b}_{B}$	$0.55 \pm 0.00^{b}_{B}$
	4	$0.77 \pm 0.01^{b}_{A}$	$0.55 \pm 0.00^{b}_{B}$	$0.54 \pm 0.01^{b}_{B}$
	5	$0.78 \pm 0.00^{a}_{A}$	$0.56 \pm 0.00^{a,b}_{B}$	$0.56 \pm 0.00^{a,b}_{B}$

[a]Each value in the table represents the mean ± standard deviation from triplicate analyses. Means within each column with different superscripts are significantly ($P < 0.05$) different. Means within each row with different subscripts are significantly ($P < 0.05$) different.

Abbreviations: System A, RBD palm olein as control; System B, Palm-based MLCT oil with 200 ppm TBHQ; System C, Palm-based MLCT oil with 1000 ppm oleoresin sage extracts.

of the medium- and long-chain triacylglycerols structure and also the presence of partial glycerides (Shimizu et al., 2004). These products are not the harmful products. Therefore, determination of total polar compounds may not be a good quality indicator for the palm-based MLCT oil since many European countries have established regularity limit of total polar compounds of 25 – 27% as the discard point for frying oil (Mellema 2003; Sanibal and Mancini-Filho, 2004). Nevertheless, all three oil systems showed significant increased ($P > 0.05$) in total polar compounds with frying days.

Sensory evaluation on fried chips indicated the stable organoleptic quality of chips fried with either RBD palm olein or palm-based MLCT oils with different antioxidant treatments (Figure 1a). The sensory data on palm-based MLCT fried chips showed no significant differences ($P > 0.05$) in terms of odor, taste, crispiness and overall acceptability compared to chips fried in RBD palm olein. To further examine the oxidative stability of fried chips, a rancidity assessment of fried chips over three months storage period was conducted and the results obtained showed no significant differences ($P > 0.05$) between chips fried in RBD palm olein and palm-based MLCT oils (Figures 1b).

The use of MLCT oil blends in salad dressings application also investigated. In this study, the salad dressings prepared using lemon juice polysaccharide solutions are of pourable consistency with reduced oil content (50%, v/v, oil-in-water emulsion). Using the same ingredients for dressing preparations, all three dressing systems was found to have similar trends of droplet size distribution, with the predominant size falling between 3 and 4 µm. The oscillation measurement was used for analyzing the visco-elastic behaviors of the soybean- and MLCT-based salad dressings. A dynamic stress sweep was applied to determine the flow properties and to estimate the degree of structural breakdown with shear. In summary, all dressing systems showed a similar trend of G' (storage modulus) and G" (loss modulus) changes versus stress steady flow. At higher stress levels, a sharp drop in G' and G" values was observed in all dressings indicated a completed breakdown of the structure (Figure 2a). The point at which the G' and G" curves cross each other can be used as an indication of mouthfeel of the salad dressings. Both soybean- (System I) and MLCT-based salad dressings (System II and III) have G' and G" curve crossing at similar stress levels of between 32.3 and 33.6 Pa (Figure 2b). In addition, soybean-based dressing showed no significant differences ($P > 0.05$) in apparent viscosity, $\eta 0$ as opposed to MLCT-based dressings with the same magnitudes of yield stress, $\tau 0$ at 17.34 Pa (Figure 2c). The shearing will cause the sample structure to break down, but at the same, time the natural behavior of the sample is to build up the structure. Hence, as a result of shearing, time dependency of a thixotropic fluid is related to the break-down or build up of its structure. In general, all dressing systems exhibited similar thixotropic profiles as showed in Figure 3. This phenomenon showed that System I, II and III displayed similar visco-elastic properties, indicating similar structural and textural properties regardless of triacylglycerols structure differences.

The quantitative descriptive analysis (QDA) of each sensory attribute of salad dressings was transformed to numeric scores ranging from 1 to 9. The trained panelist were asked to evaluate the salad dressings on the basis of color, odor, intensity, taste, viscosity, off-flavor and overall quality. The QDA study showed no significant differences ($P > 0.05$) in all the attributes except for color, in all dressing systems (Table 4). In general, soybean- and MLCT-based dressings displayed good physical appearance and organoleptic acceptability with similar textural properties.

In summary, the data obtained from these two model systems indicated that MLCT oil produced through esterification synthesis of capric, oleic acid and glycerol via Lipozyme RM IM lipase was suitable to be applied in the frying and salad dressing applications to replace palm olein or soybean oil, respectively for daily consumption. For other food applications like shortening or margarine, the type of fatty acid stock used in the MLCT production need to be changed to suite the physical and chemical characteristics requirement for particular food applications.

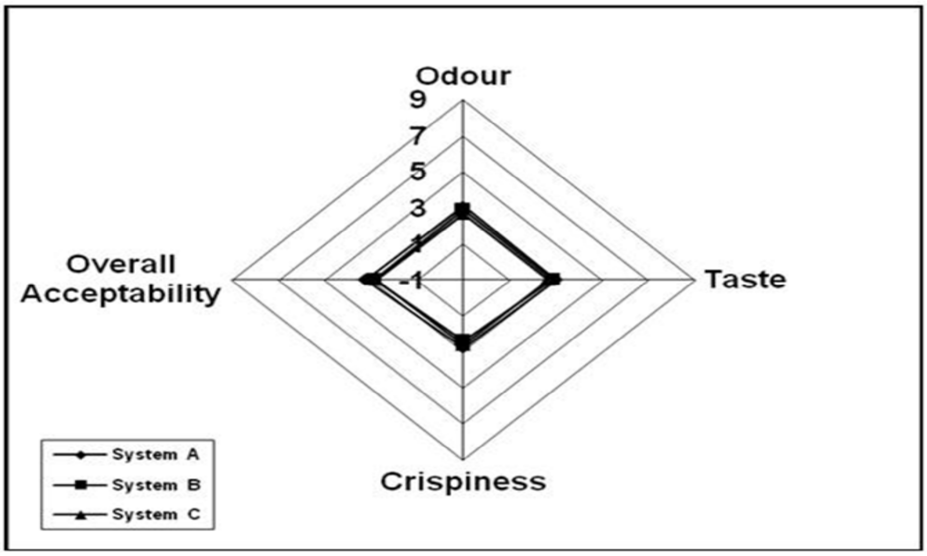
Conclusion

Exposure to continuous stressed frying operations proven that palm-based MLCT oils have better thermal and oxidative strength than RBD palm olein with the aid of natural or synthetic antioxidants. Sensory evaluation and rancidity assessment on fried potato chips revealed no significant differences ($P > 0.05$) between RBD palm olein and palm-based MLCT oils with different antioxidant treatments. The study of the rheological behaviors and sensory evaluation on soybean- and MLCT-based salad dressings revealed similar visco-elastic and organoleptic properties, indicating similar structural and textural properties. As a conclusion, MLCT oil can be incorporated in the mainstream foods, to substitute soybean oil or

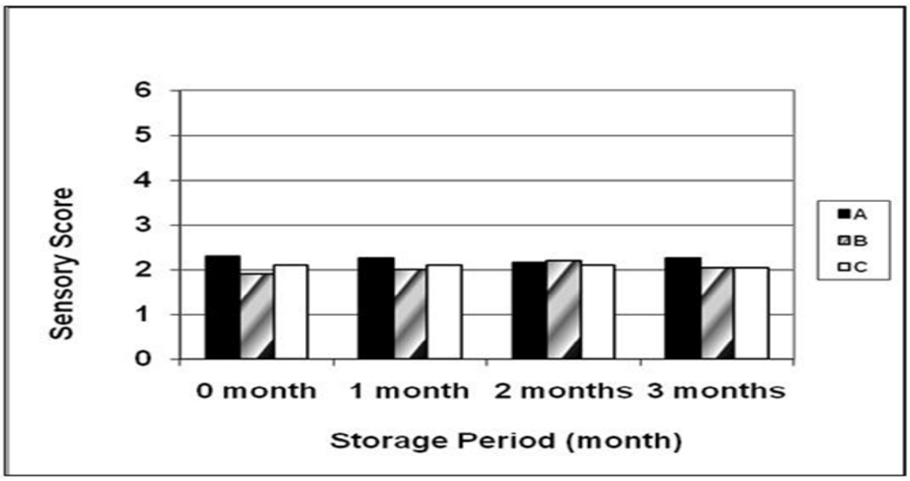
Table 4. Sensory scores for quantitative descriptive analysis of different dressing systems[a]

Sensory attribute	System I	System II	System III
Color	2.90 ± 1.10[b]	3.00 ± 0.94[b]	3.80 ± 1.03[a]
Odor intensity	4.30 ± 1.16[a]	4.10 ± 1.52[a]	4.20 ± 1.55[a]
Taste	6.60 ± 0.52[a]	6.80 ± 0.42[a]	6.30 ± 0.95[a]
Viscosity	5.50 ± 0.85[a]	5.30 ± 1.06[a]	5.20 ± 1.23[a]
Texture	2.60 ± 0.97[a]	2.70 ± 0.95[a]	2.60 ± 0.84[a]
Oiliness	3.00 ± 0.47[a]	2.90 ± 0.57[a]	3.10 ± 0.57[a]
Off-flavor	6.60 ± 0.70[a]	6.70 ± 0.67[a]	6.70 ± 0.67[a]
Overall quality	6.70 ± 0.67[a]	6.70 ± 0.67[a]	6.90 ± 0.74[a]

[a]Each value in the table represents the mean ± standard deviation from 10 observations. Means within each row with different superscripts are significantly ($P < 0.05$) different.
Abbreviations: System I, Soybean-based salad dressings as control; System II, MLCT-based salad dressings with 200 ppm TBHQ; System III, MLCT-based salad dressings with 1000 ppm oleoresin sage extracts

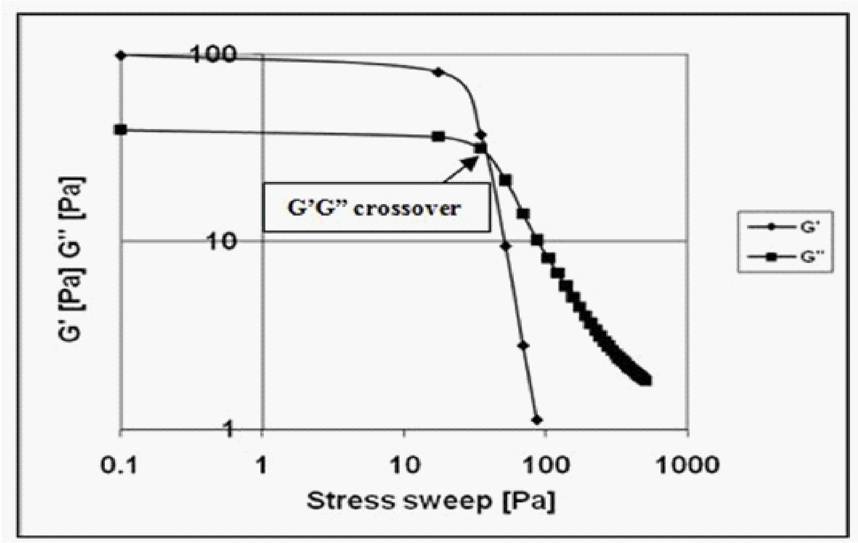


(a)



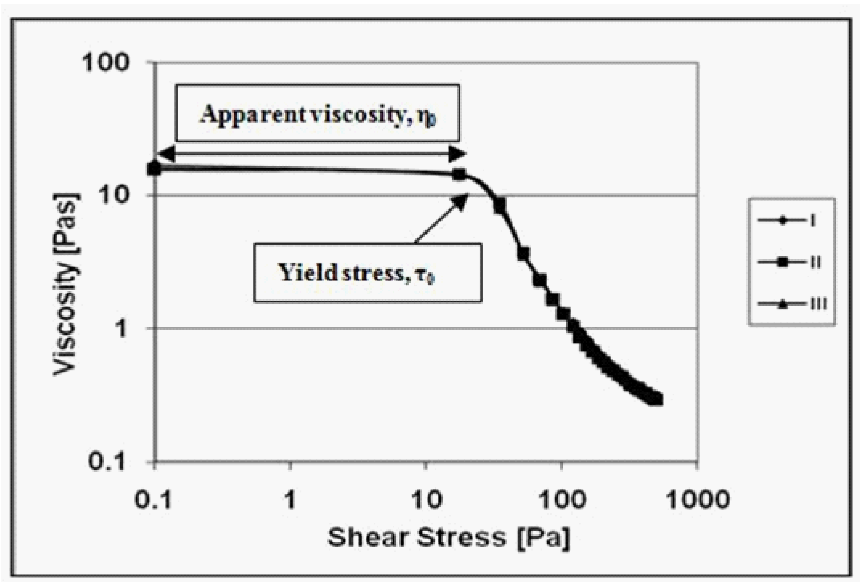
(b)

Figure 1. (a) A nine-point hedonic scale of sensory evaluation on potato chips fried in three different oil systems (1 = like extremely to 9 = dislike extremely). (b) Rancid scores of stored potato chips during storage at ambient temperature (Evaluation scale: 1 = very good to 6 = very rancid). System A, RBD palm olein as control; System B, Palm-based MLCT oil with 200 ppm TBHQ; System C, Palm-based MLCT oil with 1000 ppm oleoresin sage extracts.



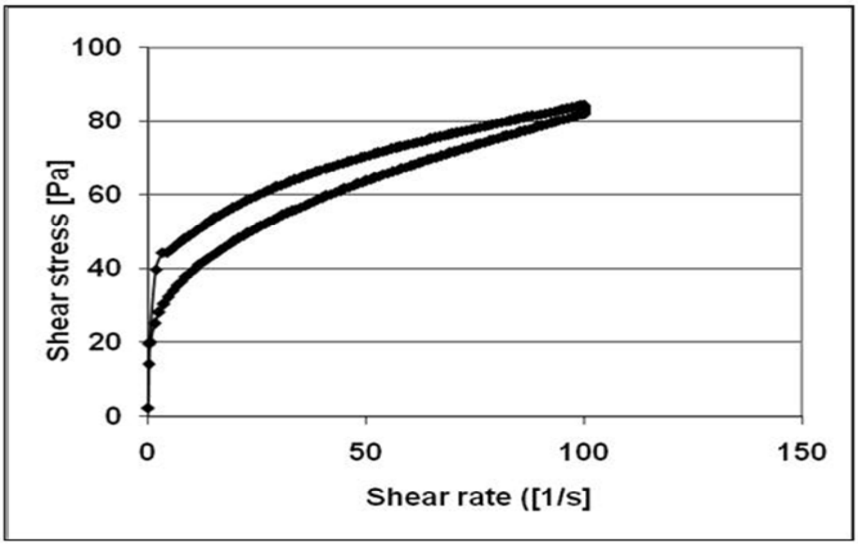
(a)

(b)

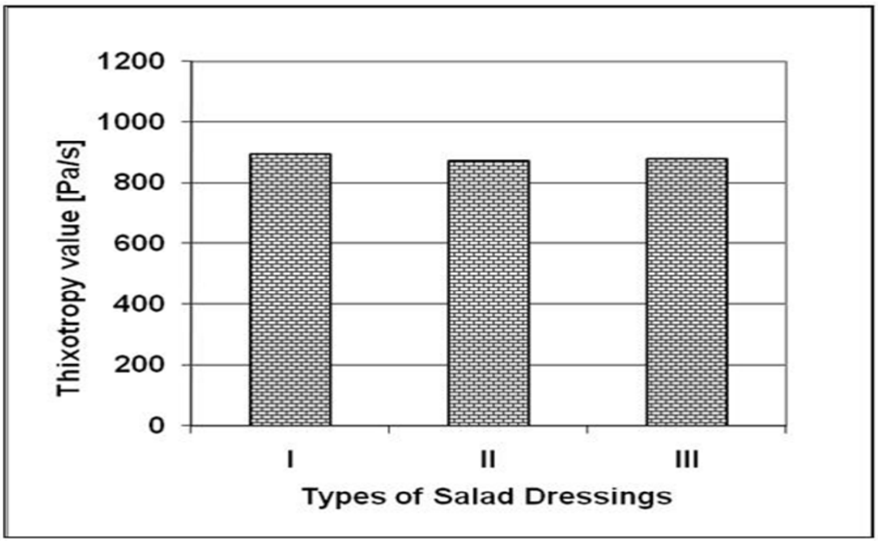


(c)

Figure 2. (a) Storage modulus (G') and loss modulus (G") vs. stress sweep conducted at frequency of 1 Hz, temperature of 4°C with stress range from 0.1 to 500 Pa on soybean-based salad dressings; (b) G' G''crossover; (c) Viscosity (Pas) vs. stress sweep (Pa) for soybean-based salad dressings (I), MLCT-based salad dressings with 200 ppm TBHQ (II), MLCT-based salad dressings with 1000 ppm oleoresin sage extracts (III)



(a)



(b)

Figure 3. (a) Time-dependent behavior as a function of the increasing/decreasing shear rate of flow curve, ramped for 0 to 100 s^{-1} on soybean-based salad dressings. (b) Thixotropy value for soybean-based salad dressings (I), MLCT-based salad dressings with 200 ppm TBHQ (II) and MLCT-based salad dressings with 1000 ppm oleoresin sage extracts (III) was determined by the 'hysteresis loop' between the up- and down-curves of a flow curve.

palm olein in salad dressing formulation and frying oil, respectively.

Acknowledgement

The authors gratefully acknowledge the R & D staffs from Golden Jomalina Food Industries Sdn. Bhd., Selangor, Malaysia for their kind technical assistance. They would like to thank Sime Darby Research Sdn. Bhd. for the financial support of this work.

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