รูปแบบรายงานวิจัยฉบับสมบูรณ์ แบบที่ 1 **(สำหรับโครงการเดี่ยวหรือโครงการย่อย)**

ส่วนที่ 1 หน้าปก

รายงานวิจัยฉบับสมบูรณ์

น้ำมันมะพร้าวบริสุทธิ์: ผลของเอนไซม์ต่อประสิทธิภาพการสกัดน้ำมัน และการศึกษาการใช้งานในผลิตภัณฑ์อาหาร

Virgin coconut oil (VCO): Effects of enzyme on oil recovery efficiency and study on utilization in food products

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ส่วนที่ 2 เนื้อหา

1. ชื่อโครงการ (ภาษาไทย): น้ำมันมะพร้าวบริสุทธิ์: ผลของเอนไซม์ต่อประสิทธิภาพการสกัดน้ำมันและการศึกษาการใช้งานในผลิตภัณฑ์อาหาร

(ภาษาอังกฤษ): Virgin coconut oil (VCO): Effects of enzyme on oil recovery efficiency and study on utilization in food products

2. คณะนักวิจัย และหน่วยงานต้นสังกัด

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บทนำ

ปัจจุบันมีความสนใจในการนำน้ำมันมะพร้าว (coconut oil, CO) มาใช้เป็นส่วนประกอบเชิงออกฤทธิ์ในอุตสาหกรรมต่างๆ ทั้งในผลิตภัณฑ์อาหาร ยา และเครื่องสำอาง เนื่องจาก CO อุดมไปด้วยกรดไขมันขนาดโซ่ปานกลางที่สามารถย่อยได้ง่าย และมีฤทธิ์ต้านไวรัส น้ำมันมะพร้าวบริสุทธิ์ (virgin coconut oil, VCO) หมายถึง CO ที่ผลิตขึ้นจากกระบวนการปราศจากสารเคมี เป็นที่นิยมในการนำมาใช้กับผลิตภัณฑ์อาหาร เนื่องจากมีกลิ่นรสตามธรรมชาติที่ดี ทั้งยังอุดมด้วยสารออกฤทธิ์ทางชีวภาพต่างๆ เช่น โทโคฟีรอล โทโคไทรอี–นอล และพอลีฟีนอลิค ที่มีประสิทธิภาพต้านออกซิเดชันที่ดี ในการวิจัยนี้ทำการศึกษาผลของวิธีการสกัดต่อประสิทธิภาพการสกัดและสมบัติเชิงเคมีของ VCO ที่ได้ โดยเปรียบเทียบระหว่างวิธีการสกัดแบบดั้งเดิม (การหมัก และการเปลี่ยนวงจรอุณหภูมิ) กับกระบวนการสกัดที่ใช้เอนไซม์ พบว่าการสกัดโดยใช้เอนไซม์อัลคาเลส (ความเข้มข้นเอนไซม์ ร้อยละ 0.3 ที่ 60 °ซ นาน 120 นาที) การหมัก (ที่ 30 °ซ นาน 36 ชั่วโมง) และการเปลี่ยนวงจรอุณหภูมิ (4 วงจร โดยแต่ละวงจรประกอบด้วยการแช่แข็งที่ -20 °ซ นาน 30 นาที การบ่มที่อุณหภูมิห้อง นาน 10 นาที และการให้ความร้อนที่ 60 °ซ นาน 10 นาที) ให้ร้อยละการสกัดน้ำมันเป็น 93.5 74.9 และ 79.0 ตามลำดับ การสกัดโดยเอนไซม์อัลคาเลสให้ VCO ที่มีกรดไขมันไม่อิ่มตัวในปริมาณสูงกว่าน้ำมันที่ได้จากกระบวนการสกัดแบบดั้งเดิม นอกจากนี้ VCO ที่ได้จากกระบวนการสกัดด้วยเอนไซม์นั้นยังมีคุณภาพเริ่มต้นที่ดีกว่า บ่งชี้จากค่าเพอร์ออกไซด์ และปริมาณกรดไขมันอิสระที่ต่ำกว่า ส่วนปริมาณสารฟีนอลิคนั้นพบได้มากที่สุดใน VCO ที่สกัดด้วยวิธีการหมัก โดยสารประกอบฟีนอลิคที่พบมากได้แก่ คาเทชิน กรดแกลลิค กรดวานิลิค และกรดพาราคูมาริค อย่างไรก็ตาม VCO ที่ผลิตได้จากกระบวนการหมักนี้มีกลิ่นหมัก เมื่อพิจารณาจากกลิ่นรสธรรมชาติที่เป็นที่ต้องการ และประสิทธิภาพในการสกัดน้ำมันได้สูงสุดแล้ว ดังนั้นจึงเลือกกระบวนการสกัดด้วยเอนไซม์อัลคาเลสมาใช้เตรียม VCO ในการทดลองต่อไป

จากนั้นศึกษาการนำ VCO มาใช้ประโยชน์ โดยเลือกน้ำสลัดเป็นตัวอย่างศึกษา ทำการศึกษาความคงตัวทางเคมีกายภาพของน้ำสลัด VCO เทียบกับน้ำสลัดที่เตรียมจากน้ำมันถั่วเหลือง (soybean oil, SBO) และศึกษาผลของการใช้มอลโตเดกซ์ทรินจากมันสำปะหลัง (tapioca maltodextrins, TMD) โดยผันแปรระดับค่าสมมูลเดกซ์โตรส (dextrose equivalent, DE) ได้แก่ DE 9 12 และ 16 และความเข้มข้น ได้แก่ ความเข้มข้นร้อยละ 0.5 1.5 และ 3 ของ TMD ที่เติมลงไป พบว่าความคงตัวทางกายภาพของน้ำสลัด VCO และ น้ำสลัด SBO มีความใกล้เคียงกัน แต่ น้ำสลัด VCO แสดงความคงตัวต่อการเกิดออกซิเดชันที่ดีกว่าน้ำสลัด SBO อย่าง

ชัดเจน ปริมาณสารฟีนอลิคพบได้มากกว่าในน้ำสลัด VCO การใช้ TMD ที่ระดับ DE 9 ส่งผลช่วยพัฒนาความคงตัวทางกายภาพของน้ำสลัด โดยเฉพาะเมื่อใช้ TMD ดังกล่าวในระดับความเข้มข้นที่สูงขึ้น โดยการใช้ TMD ส่งผลช่วยชะลอการเปลี่ยนแปลงค่าพีเอชและสีของน้ำสลัดได้ระหว่างการเก็บรักษานาน 8 สัปดาห์ จากการทดสอบทางประสาทสัมผัสพบว่า น้ำสลัด VCO และ น้ำสลัด SBO ที่เติม TMD ระดับ DE 9 ปริมาณร้อยละ 3 มีคะแนนการยอมรับที่ไม่แตกต่างกัน การทดลองครั้งนี้แสดงให้เห็นว่า VCO สามารถนำมาใช้เตรียมน้ำสลัดที่มีความคงตัวทางเคมีกายภาพที่ดีทั้งยังให้ปริมาณสารฟีนอลิคที่สูงอีกด้วย

ในการศึกษาส่วนสุดท้ายนั้น นำ CO มาใช้พัฒนาความคงตัวต่อการทอดของ SBO ผ่านทางเทคนิคการผสม โดยนำ SBO มาผสมกับ CO ที่อัตราส่วน SBO:CO โดยปริมาตรต่างกันดังนี้ 100:0 80:20 60:40 และ 50:50 ก่อนนำน้ำมันผสมดังกล่าวไปใช้ในการแปรรูปนักเกตไก่ และเฟรนช์ฟราย ที่จำนวนครั้งของการทอดซ้ำต่างๆกัน พบว่าการผสม CO ในอัตราส่วนที่เหมาะสม ส่งผลช่วยพัฒนาความคงตัวต่อความร้อนของ SBO ได้สำเร็จ ซึ่งการพัฒนาความคงตัวต่อความร้อนของน้ำมันทอดนี้ยังช่วยทำให้ลักษณะของผลิตภัณฑ์อาหารที่ผ่านการทอดดีขึ้นอีกด้วย บ่งชี้จากการลดลงของการดูดซับน้ำมัน รวมถึงการรักษาสีและลักษณะเนื้อสัมผัสที่ดีกว่าตลอดการทอดซ้ำ โดยอัตราส่วนผสมที่เหมาะสมที่สุดต่อการพัฒนาเสถียรภาพต่อความร้อนของน้ำมัน และลักษณะที่ดีของผลิตภัณฑ์อาหารที่ได้จากการศึกษาครั้งนี้คือ อัตราส่วนผสมที่ 60:40

Abstract

Recently, there is growing interest in using coconut oil (CO) as a functional ingredient in many industries including food, pharmaceuticals, and cosmetics, because of its abundant presence of medium chain fatty acids with a good digestibility and antiviral activity. Virgin coconut oil (VCO), defined as the CO recovered through the process without chemical treatment, has become popularity for food applications, regarded due to its natural sweet taste and nutty flavor as well as abundant presence of neutraceutical components, such as tocopherol, tocotrienol, and polyphenols with a good antioxidant capacity. In this work, effect of oil extraction method on recovery efficiency and chemical properties of the VCO was studied, comparing between traditional means, *i.e.*, fermentation and thermal cycling techniques, and enzyme–aided means. By using alcalase–aided (0.3 % v/v at 60 °C for 120 min), fermentation (at 30 °C for 36 h), and thermal cycling (4 cycles, in which 1 cycle consists of 6 h of freezing at -20 ºC, 30 min of incubation at room temperature, and 10 min of heating

at 60 °C) techniques, the oil recovery yields were 93.5, 74.9 %, and 79.0 %, respectively. Alcalase–aided extraction provided the VCO with higher amount of unsaturated fatty acids compared to the oils extracted by traditional techniques. Moreover, the VCO recovered through protease–assisted means showed a greater initial quality as suggested by the lowered peroxide value and free fatty acid content. The highest amount of phenolic compounds were observed for the VCO prepared by fermentation technique, in which the phenolic compounds predominantly found were catechin, gallic, vanillic, and *p*-coumaric acids. However, the fermented off–odor was detected for the VCO recovered through fermentation means. Considering on the present natural flavor and highest oil recovery yield, alcalase–aided extraction was selected to prepare VCO in the further work.

Next, utilization of VCO was studied using salad dressing as a model. Physicochemical stability of the VCO dressings were studied in comparison with the dressings made from soybean oil (SBO). Effect of tapioca maltodextrins (TMD) on the characteristics of dressing samples was also elucidated, by varying the dextrose equivalent (DE), *i.e.*, DE of 9, 12, and 16, and concentrations, *i.e.*, 0.5, 1.5 and 3 %, of the TMD. A comparable colloidal stability between VCO and SBO dressings was observed. Nonetheless, higher oxidative stability of VCO samples than did SBO counterparts was markedly evident. The higher content of phenolic compounds was found for the VCO dressing. Improvement on dispersibility of the dressings could be accomplished by incorporating TMD at DE 9, especially at increased concentration. TMD could also maintain pH and color changes of the dressings during a storage of 8 weeks. Comparable sensorial acceptability between the VCO and SBO dressings was observed in a presence of 3 % TMD (DE 9). The present study suggested that VCO could be employed to prepare salad dressing with desirable physicochemical stability and enriched phenolic compounds.

Finally, CO was employed to improve frying stability of SBO via blending technique. SBO was blended with CO at various ratios, *i.e.,* SBO:CO mixing volume ratios of 100:0, 80:20, 60:40, and 50:50, before using to cook chicken nuggets and French-fries at various repeated frying cycles. Improvement on thermal stability of SBO could be accomplished via blending

with CO at the appropriate ratio. Development on thermal tolerance of the oils led to improve the characteristics of fried food materials, as suggested by decreasing in fat adsorption and retained color and texture attributes along repeating frying process. In the present work, the suitable blending ratio between SBO and CO providing the oils with the greatest thermal tolerance and most desirable fried food characteristics was 60:40.

1. Introduction

Recently, coconut oil is growing in popularity to be employed as a functional ingredient in many industries, including food, pharmaceuticals, and cosmetics because of its various health benefits, *e.g.*, rich in medium chain fatty acids (MCFAs), good digestibility, and exhibit antiviral activity (Che Man and Marina, 2006; Marina *et al.*, 2009a). Generally, coconut oil is extracted by dry process with rather low oil recovering efficiency (*ca*. 40-60 %, Sharma *et al*., 2002). Solvent extraction is a promising way to harvest oil from plants with a better oil recovery capability, *ca.* up to 90 %. Solvent extraction, however, has inherent disadvantages of high cost, energy consuming, pollutant creating, and leaving low quality of oil cake (Jiang *et al.,* 2010). The oils received from dry and solvent extraction, moreover, have to be further treated by refining, bleaching, and deodorizing (RBD) process (Marina *et al.,* 2009a). The RBD operation, especially for deodorizing, is always conducted at high temperature of *ca.* 204–245 °C that affects to deteriorate oil quality (O'Brien, 2004), by liberating high free fatty acid content. To tackle these drawbacks, a wet method carried out by extraction emulsion milk from fresh coconut meats, before breaking it to liberate the oil, is introduced (Marina *et al.,* 2009a). By using the wet extraction, high temperature and solvent, and RBD process can be omitted (Villarino *et al.,* 2007). The wet extraction, therefore, is a practical way to reduce investment cost and energy requirement. The wet extraction, moreover, can be regarded as an eco-friendly method since no used solvent residue. The coconut oil produced from this technique is called virgin coconut oil (VCO) defined as the oil obtained from fresh, mature coconuts without any chemical refining (Shilhavy and Shilhavy, 2004; Villarino *et al*., 2007). With an absence of chemical treatment, VCO has a natural sweet taste and nutty flavor which are not observed in the RBD oils (Villarino *et al*., 2007). Nevin and Rajamohan (2004)

suggested superior health benefits of VCO in term of neutraceutical components than did the RBD treated ones. VCO retains high content of unsaponifiable matters, *e.g.,* tocopherol, tocotrienol, and polyphenols, proven to be a good antioxidant agent that might provides health benefits for consumers (Dia *et al*., 2005; Seneviratne *et al*., 2009). From all points of view, both of better sensory characteristic and higher nutritive value were guaranteed for VCO than the dry or solvent extracted oils. This concept leads to increase the attractive of VCO utilization as a functional ingredient in food processing.

To recover VCO, the wet process is always conducted to extract coconut milk, and oil recovering is further accomplished by destabilizing the milk emulsion. Oil liberating through emulsion destabilization can be conducted through various techniques, *i.e.,* heating, fermentation, and freeze-thaw cycling. By using traditional methods, *i.e.,* fermentation and heating, low oil recovery, *ca*. 30–40 %, with a rather poor oil characteristic, was always provided. It was reported that the VCO derived by the traditional methods contained high content of moisture and free fatty acids that led to shorten shelf-life and impair qualities of the oils, such as promoting oxidative rancidity and degradation of the oils when used in frying process (Che Man *et al.,* 1996, 1997; Raghavendra and Raghavarao, 2010). In the past decade, enzyme assisted extraction has been emerged to recover oil from various plants. By applying enzyme, oil recovery efficiency was successfully improved with a good quality of the oils and pressed cake. Enzyme assisted process, moreover, is an eco-friendly means (Sharmar *et al.,* 2002). By using different recovering technique, chemical compositions were different effecting to functional properties and qualities of the derived oils. Nearly seven-times higher in the amount of phenolic compounds were found in VCO recovered through heating than that prepared by pressing method (Seneviratne and Dissanayake, 2008). Moreover, the phenolic species with more complex structure were found for the former than the latter oils (Seneviratne and Dissanayake, 2008). In sesame oil, however, thermal treatment affected to lower amount of bioactive compounds, *i.e.,* lignans and sesamol (Konsoula and Liakopoulou-Kyriakides, 2010). Regarding coconut oil, information about physicochemical properties of VCO derived by different means has been not well

elucidated. To recover VCO via enzyme assisted process, moreover, scientific data are still rather restricted. In the present work, study on the improvement of VCO recovering efficiency was conducted through enzyme-assisted process. Then, physicochemical properties of the oils were determined comparing with the VCO produced by the traditional methods. This work aimed to establish the effective condition providing VCO with high recover yield and good oil quality, and to fulfill the scientific information about characteristics of VCO derived by different methods.

Regarding utilization of fats and oils in food products, dispersing of oil in a form of emulsion and frying process were focused in the present study. Emulsion, defined as a dispersion of two immiscible liquids, is widely found as a composition in various products, *e.g.,* salad dressings, beverages, sauces, and so on. Salad dressings are one of the most popular emulsified foods. Stability of dressings is mainly governed by both physical, *i.e*., phase separation, and chemical, *i.e*., lipid oxidation, factors. Nowadays various attempts are made in order to produce emulsions with nutritive ingredients. VCO with high contents of MCFAs and bioactive compounds (Dia *et al*., 2005; Seneviratne *et al*., 2009) might be a potent candidate to prepare emulsified products with desirable stabiltiy. With higher polarity than those long chain counterparts, MCFAs could provide interfacial activity, and led to improve colloidal stability of dressings (Driscoll *et al*., 2001; Granger *et al*., 2005; Nor Hayati *et al.,* 2007). Due to its high saturation degree and rich in unsaponified matters, *e.g.,* tocopherol, tocotrienol, and polyphenols (Dia *et al*., 2005; Seneviratne *et al*., 2009), good stability against lipid oxidation and health benefits of the VCO dressings could be supposed. Dissimilar in a type of oil phase, however, effected to characteristics of the emulsified products (Nor Hayati *et al.,* 2007; Protonotariou *et al*., 2013). Consequently, this study aimed to investigate physicochemical stability of dressings using VCO as a dispersed phase. Soybean oil (SBO), which is the all-purpose oil widely used in Thailand, was also employed to prepare dressing, in comparing with the VCO dressing. To ensure product stability, moreover, effect of tapioca maltodextrin (TMD) on stability of the dressing samples was reported at varying dextrose equivalent (DE) values and concentrations. By using TMD as stabilizer in the

dressing recipe, it might be a practical way to gain valuable of tapioca, which is one of the important agricultural products of Thailand.

Deep frying is a conventional process popularly used to prepare food stuffs. Oils are always employed as a heating medium in such a process, where they are exposed to elevated temperature with a presence of oxygen and water (Romero *et al*., 2006; Alireza *et al*., 2010). This extreme condition affected to deteriorate oil quality by liberating various decomposed compounds, *e.g*., aldehyde, peroxides, and polar substances (Stevenson *et al*., 1984; Romero *et al*., 2006; Alireza *et al*., 2010). Upon frying, moreover, bioactive compounds tended to be degraded (Gómez-Alonso *et al.,* 2003; Juárez *et al*., 2011). These phenomena led to inferior oil quality in technological, sensorial, as well as nutritional aspects. It has been suggested that unsaturation degree of oils affected to enhance oil deterioration during frying process (Velasco and Dobarganes, 2002; Gómez-Alonso *et al.,* 2003; Alireza *et al*., 2010; Marmesat *et al.,* 2012). Reduction in unsaturation degree through partial hydrogenation and oil blending has been conducted to improve thermal stability of oils. Partial hydrogenation, however, might generate *trans*-fatty acids which are well recognized as unhealthy lipids (Marmesat *et al*., 2012). Oil blending, carried out by mixing high saturated oils such as palm olein to unsaturated ones, could effectively reduce unsaturated degree of some vegetable oils, thereby improving their frying stability (Chu and Kung, 1998; Normand *et al.,* 2001, 2006; Pangloli *et al*., 2002; Naz *et al.,* 2005; Farhoosh *et al*., 2009; Alireza *et al*., 2010; Juárez *et al*., 2011; Sunisa *et al*., 2011; Marmesat *et al.,* 2012; Ramadan and Wahdan, 2012). With abundant presence of unsaturated fatty acids, SBO is rather prone to degradation during frying process. This work aimed to enhance frying stability of SBO via blending technique using coconut oil. Coconut oil is interested candidate to achieve this goal, regarded due to its richness in saturated fatty acids and also endogenous phenolic compounds. Recently, study on oil blending technique has been intensely conducted by using some vegetable oils, involving canola and sunflower oils (Normand *et al.,* 2001, 2006; Pangloli *et al*., 2002; Farhoosh *et al*., 2009; Alireza *et al*., 2010; Juárez *et al*., 2011; Marmesat *et al.,* 2012), whereas study on SBO stability are rather constrained. The final part of this

work aimed to investigate effects of coconut oil blending on frying stability of SBO. In frying process, different food commodities, *i.e*., protein– and carbohydrate–based foods, were employed as a model, and their effects on thermal stability of the blended oils during frying process were also reported.

2. Objectives

- To study on the effects of enzyme assisted extraction process on the recovering efficiency of VCO

- To examine physicochemical characteristics of VCO derived from enzyme assisted process compared with the oils extracted by conventional methods, *i.e*., fermentation and thermal-cycling processes

- To study on physicochemical stability of salad dressing prepared by using VCO as a dispersed phase, in comparison with the recipes prepared using SBO

- To observe the effects of TMD at various DE and concentrations on physicochemical stability of the VCO and SBO salad dressings

- To improve stability of SBO in deep frying process via blending technique with coconut oil

- To examine the effects of different food commodities, *i.e.,* carbohydrate based– and protein based–products, on stability of the blended oils during frying process

3. Literature Review

3.1 Coconut oil (CO)

CO is an edible oil that has been consumed in tropical regions for thousands years. CO has a natural sweet taste and contains most of saturated fatty acids in which mostly are medium chain species. Fatty acid composition of CO is illustrated in Table 1 by comparing with some selected vegetable oils. Due to its richness in saturated fatty acids, CO tends to more susceptible against lipid oxidation than other seed oils that might be useful for some applications, such as grazing material in food product. The medium chain fatty acids

(MCFAs), moreover, are easily metabolized, so CO is an attractive energy source for some people, *e.g.*, patients and immature babies (Paramita *et al*., 2012).

Table 1 Fatty acid compositions (% of total fatty acids) of some selected vegetable oils

Fatty acids	coconut	canola	corn	olive	palm olein	palm kerne	rape seed	soy bean	sun flower
Saturated fatty acids (SFAs)									
C6:0	-	-	-	-	-	0.2	-	-	-
C8:0	7.1	-	-	-	-	4.0	-	-	-
C10:0	7.3	-	-	-	-	3.9	-	-	-
C12:0	54.0	-	-	-	-	50.4	-	0.1	-
C14:0	17.4	0.1	-	-	2.5	17.3	0.1	0.3	-
C16:0	6.1	5.7	11.1	11.0	4.8	7.9	2.9	10.8	6.0
C18:0	1.6	2.1	1.8	2.2	3.6	2.3	1.4	3.2	4.0
C20:0	-	0.2	0.2	-	-	-	-	0.1	-
C22:0	-	0.2	-	-	-	-	0.5	0.1	-
Total SFAs	93.5	8.3	13.0	13.2	49.6	86.0	4.9	14.6	10.0
Unsaturated fatty acids (USFAs)									
C18:1	5.0	57.7	25.3	72.5	45.2	11.8	33.0	24.0	18.0
C418:2	1.3	24.6	60.1	7.9	7.9	2.1	15.4	54.4	70.0
C18:3	-	7.9	1.1	0.6	-	-	6.2	6.8	-
C20:1	-	1.0	-	0.3	-	-	12.2	-	-
C22:1	-	0.2	-	-	-	-	25.5	-	-
Total	6.3	91.4	86.5	81.3	53.1	13.9	92.3	85.2	88.0

From: Abraham and Horn (1992)

The physical characteristics of oils are important factors determining their utilization in food processing. Table 2 shows the selected physical properties of CO in comparing with other vegetable oils.

Table 2 Physical characteristics of some selected vegetable oils

oils	melting point (°C)	density (25°C)	refractive index
coconut	23 to 26	0.917 – 0.919	1.448 – 1.450
corn	-10 to -12	0.922 – 0.926	1.465 – 1.468
cotton seed	-2 to 2	0.916 – 0.918	1.458 – 1.466
olive	-3 to 0	0.909 – 0.915	1.466 – 1.468
palm	33 to 40	0.921 – 0.925	1.449 – 1.455
palm kernel	24 to 26	0.860 – 0.873	1.452 – 1.458
sesame	-4 to 0	0.920 – 0.926	1.470 – 1.474
soybean	-20 to -23	0.924 – 0.928	1.466 – 1.470
sunflower	-16 to -18	0.922 – 0.927	1.467 – 1.469

From: Pike (1994)

3.2 Properties and benefits of virgin coconut oil (VCO)

Currently, VCO consumption is growing significantly for food purposes as functional oil. VCO, recovered by a lack of heating and chemical treatment, is believed to healthier than refined bleached and deodorized (RBD) oil (Marina *et al*., 2009a). High thermal treatment used in RBD process affected to destroy some nutritive substances (Marina *et al*., 2009a). By preparing through a mild condition, VCO is rich in unsaponified matters involving tocopherol, tocotrienol and polyphenols, which are proven to be effective antioxidant agents (Dia *et al*., 2005; Seneviratne *et al*., 2009; Raghavendra and Raghavarao, 2011). The major phenolic

compounds present in VCO were protocatechuic, vanillic, caffeic, syringic, ferulic, and *p*-coumaric acids (Seneviratne and Dissanayake, 2008; Marina *et al*., 2009b). Without chemical treatment, moreover, VCO tended to have mild and pleasant flavor with a water-like clear appearance.

The major fatty acid components of VCO is MCFAs, especially lauric (C12:0) and myristic (C14:0) acids with the available content of *ca*. 50 and 22 %, respectively. Other fatty acids present in VCO are caprylic acid (*ca*. 3 %), capric acid (*ca*. 5 %), and long chain counterparts, *e.g*., palmitic, stearic, oleic, and linoleic acids (*ca*. 20 %) (Raghavendra and Raghavarao, 2011). Many health benefits of MCFAs have been reported, such as antiviral, antibacterial, and antifungal functions (German and Dillard, 2004). The oils with high MCFAs content, are useful for some people, regarded due to rapid offering energy conversion compared to long chain counterparts. The majority of MCFAs is directly transported through a portal vein, so they can increase caloric burning and produce more energy (Toyosaki *et al*., 2008; Matulka *et al.,* 2009). VCO with a high content of MCFAs, therefore, is expected to be useful nutritional oil for postoperative patients and immature babies (Paramita *et al*., 2012). Considering on abundant presence of MCFAs, VCO might be advantageous for dissolving flavor and liposoluble substances, *e.g*., limonene and fat soluble vitamins (Paramita *et al*., 2012). With their higher polarity compared to the long chain residues, moreover, MCFAs possessed some functional properties, *e.g.,* interfacial and emulsifying activity (Granger *et al*., 2003; Nor Hayati *et al*., 2007). With less content in unsaturated fatty acids than the other seed oils such as soybean, sunflower, canola, and corn oils, better stability against lipid oxidation of VCO could be expected, which might be useful for application in oxidative sensitive foods, such as emulsified products (Waraho *et al.,* 2011).

3.3 Destabilization of coconut milk emulsion

Various techniques are conducted to recover CO, either by dry or wet process. To produce VCO, wet process, conducting by extraction coconut milk from cleaned, dried, and grafted coconut meats before destabilizing the milk emulsion, is generally carried out. The coconut milk is naturally present in a form of oil-in-water (O/W) emulsion, which is stabilized

by proteins, *e.g*., globulin and albumins, and phospholipids (Tangsuphoom and Coupland, 2008). To provoke oil liberation from the cream, various techniques are applied including:

I. Fermentation: A traditional method conducting by fermenting the coconut milk for 24–36 h. Upon gravitational force (Raghavendra and Raghavarao, 2010) and activity of airborne lactic acid bacteria (Srivastava and Semwell, 2015), oil part is allowed to separate. Afterward, the derived oil is slightly heated for a short time to remove moisture, before finally with filtration (Madhavan *et al*., 2005). This method always gave low recovering efficiency and such a fermented odor was present affecting to mask a natural desirable flavor of CO. High moisture content of the derived oil, moreover, affected to promote oxidative deterioration during storage, and impair oil stability in further utilization such as frying (Koh and Long, 2012).

II. Heating: Partial denaturation of proteins stabilizing the coconut cream could result in oil separation, by facilitating coalescence between oil droplets (Raghavendra and Raghavarao, 2010). Cause from heating, proteins underwent conformational changes by exposing hydrophobic amino acid residues to a molecular exterior, thereby enhancing attractive force between oil drops and then promoting oil drop aggregation (Jirapeangtong *et al*., 2008). Kwon *et al*., (1996) suggested that coconut proteins were denatured at the temperature above 80 °C. Raghavendra and Raghavarao (2010) could recover VCO with a maximum yield by elevating temperature to 90 °C. Nonetheless, oil quality was inferior by thermal treatment, because high content of free fatty acids were generated through hydrolysis activation. This was responsible for undesirable flavor and less stability of the derived oil (Abdulkarim *et al*., 2006; Raghavendra and Raghavarao, 2010, 2011). Increased amount of free fatty, moreover, corresponded to lower smoking point of the oil, which is one of the undesirable characteristics for frying purpose (Koh and Long, 2012).

III. Chilling/freezing and thawing cycle: The coconut milk emulsion could be broken down by temperature changing, and centrifugation is then always incorporated to accelerate oil separation. The emulsion might be centrifuged before chilling (10 °C) or freezing (- 4 °C), in order to allow tight packing of oil drops, consequently thawing was conducted at 40 °C till the temperature of coconut cream reached to room temperature (Seow and Gwee, 1997). Raghavendra and Raghavarao (2010) reported improve oil recovery yield by reducing temperature in chilling step: The recovering yield was *ca*. 92, 74, and 65 % after chilling for 6 h at 5, 15, and 20 °C, respectively. By lowering temperature, CO was solidified and during

thawing the oil globules tended to loss their spherical shape, so coalescence was proceeded, resulting in liberating oil residue from emulsified matrix (Raghavendra and Raghavarao, 2010, 2011; Marina *et al*., 2009a).

IV. Enzyme treatment: There are many attempts applying enzymes to develop oil recovery from plants as reviewed in the following part.

3.4 Oil extraction via enzyme assisted process

Oil mainly exists in plant cells as a pocket enveloped by lipoprotein layers called lipid bodies (Sharma *et al.,* 2001). By using enzymes, oil liberating from plant cellular matrix could be enhanced. Carbohydrases, *e.g*., cellulases and pectinases could break down cell wall, while proteases enhanced permeation through liposome membrane, resulting in improved oil liberating from plant cells (Rosenthal *et al.,* 1996; Che Man *et al.,* 1996). Proteolytic enzymes facilitated disruption of cytoplasmic network by degrading fibrous proteins covering around oil bodies and made an inner structure to less tightly compact, thereby enhancing oil separation f from plant cells (Rosenthal *et al*., 1996; Jiang *et al*., 2010). Through enzyme assisted extraction, good quality of protein meal in deoiled residue was given which might be beneficial for further utilization (Sharma *et al*., 2001; Marasabessy *et al*., 2011). Upon enzyme treatment, oil qualities were affected. Raghavendra and Raghavarao (2010) found higher content of short chain fatty acids present in CO extracted by the aid of enzyme than the RBD treated ones. It should be noted that CO with better health benefit was supposed with a presence of higher short chain fatty acid content (Raghavendra and Raghavarao, 2010). Xylanase could facilitate hemicelluloses degradation in cell wall structure, so oil recovery from *Jatropha curcas* could be successfully improved (Marasabessy *et al*., 2011). Oil liberating from *J. curcas* could also be developed via protein degradation by protease produced from *B. lichenniformis* (Marasabessy *et al*., 2010). By using alcalse, recovery yield of peanut oil could be increased to the maximum efficiency of 73.45 % (Jiang *et al.,* 2010). Oil recovery from rice bran could be successfully improved using enzyme aided extraction: The extraction yield was increased up to 76 % by using protease and cellulase in combination, whereas a conventional aqueous extraction provided only 8 % in yield (Sharma *et al*., 2001). This is in accordance with other researches reporting improved oil

recovery efficiency by employing proteases and carbohydrases in combination. Abdulkarim *et al*., (2006) successfully improved oil recovery from *Moringa Oleifera* to more than 74 % using protease (Neutrase) and carbohydrases (Termamyl, Celluclast, and Pectinex). Aparna *et al*., (2002) got the highest recovery yield of 86 % using Protizyme to extract oil from peanut seeds. Combination of protease, cellalase, and hemicellulase could effectively recovery oil from copra since degradation of composited polysaccharides in coconut cell walls (Tano-Debrah and Ohta, 1997), which mainly are mannans (61 %) followed by cellulose, arabinoxylogalactan, galactomannan, arabinomannogalactan, and galactoglucomannan in a descending order of proportions (Saittagaroon *et al*., 1983). Che Man *et al.*, (1996) used combination of enzymes, *i.e*., cellulase, polygalacturonase, protease, and α-amylase, to improve CO recovery: When the enzymes were applied, the oil recovery yield was increased from 19.3 % to 73.8 % with a good quality of the derived oil, *i.e*., low moisture (*ca*. 0.11 %) and free fatty acid (*ca*. 0.051 %) contents. Development on the extraction of CO was also observed by using polygalacturonase, amylase, and protease (McGlone *et al.,* 1986). Raghavendra and Raghavarao (2010) observed the synergistic effect between enzyme treating and chilling which could raise oil recovery from coconut up to 94.5 %.

Enzyme type and extraction condition, *e.g.,* temperature, pH, enzyme concentration, and material to solvent ratio, crucially affected to oil recovery efficiency as well as physicochemical properties of the derived oils (Aparna *et al*., 2002; Abdulkarim *et al*., 2006; Jiang *et al.,* 2010). Abdulkarim *et al*., (2006) reported that heating at 45 °C was effective to recover oil from *Moringa Oleifera*, whereas the optimum temperature to recover oil from peanut was 40 °C (Aparna *et al*., 2002). Although various enzymes were employed to improve CO extractability in the previous works, the physicochemical properties and chemical compositions, *e.g.,* fatty acids and bioactive compounds, of the derived oils have been not clearly elucidated.

3.5 Physicochemical properties and stability of salad dressings

Stability of oils is crucially depended on their chemical compositions, including composited fatty acids and present miscellaneous compounds, *e.g.,* endogenous phenolic

compounds. It is well recognized that unsaturated fatty acids (USFAs) are susceptible to chemical deterioration, especially lipid oxidation, leading to inferior oil quality in sensory, nutrition, and safety aspects (Nor Hayati *et al*., 2005; Ramadan and Wahdan, 2012).

Salad dressing, a semi-solid acidic O/W emulsion, is one of the most popular consumed foods. Acceptation in salad dressing is determined by a smooth appearance, creamy texture, and pleasant flavor characteristics (Ma and Barbosa-Canovas, 1995). Salad dressing generally contains high oil content, *ca.* 20–65 % with a crowd accumulation of oil droplets giving the interaction between the adjacent droplets became important (Pal, 1997). Rheological properties and stability of salad dressing were appreciably important factor controlling quality of the product (Dickinson 2003; Nor Hayati *et al*., 2007). Regarding stability of dressing, physical and chemical deterioration has a crucial role. Dressing product should able to retard phase separation for an appreciable time to provide desirable homogeneous creamy texture, which could be provided by a weak-gel like forming of particle network (McClements, 1999). Chemical reaction, especially lipid oxidation, is considered to be a predominant cause of quality deterioration, because oil is a major component in such a product. As dispersed in an emulsified state, oxidation of lipids underwent mechanistically different from that of bulk oils (Paraskevopoulou *et a*l., 2007). Emulsified system is greatly sensitive to lipid oxidation, because a presence of large interfacial areas allowing the interaction between water soluble pro-oxidant and lipids phase (Waroho *et al*., 2011). Lipid oxidation could cause alterations in characteristics of the product, including appearance, texture, shelf-life, and also nutritional profile (Min and Boff, 2002). To prepare salad dressing with appreciable characteristics, consequently, both physical and chemical stability have to be concerned.

Emulsifier is an important tool to maintain physical stability of salad dressing (McClements, 1999; Paraskevopoulou *et al*., 2007; Perez *et al*., 2009; Nor Hayati *et al*., 2009). Proteins and carbohydrates are generally employed as emulsifier to stabilize emulsified foods. Due to their amphiphilic nature, proteins could be rapidly adsorbed to drop surfaces and facilitate emulsion formation (Cheetangdee *et al*., 2011). However, dependence on

environmental conditions such as pH, temperature, and ionic strength makes obscurity for application of proteins in food products (Perez *et al*., 2009; Cheetangdee *et al*., 2011). Polysaccharides controlled structure, texture, and stability of emulsion by imparting a sufficiently thick continuous phase that inhibited dispersed drop aggregation (Nor Hayati *et al*., 2009; Udomrati *et al*., 2013). By using in combination, proteins and carbohydrates might effectively enhance stability of emulsified food products (Dickinson, 2003). Phase separation of olive oil dressing could be retarded by increasing concentration of xanthan gum and whey protein concentrate (Protonotariou *et al*., 2013). Apparent viscosity of salad dressing was significantly increased by adding carboxy methyl cellulose (CMC), resulting in stability of the sample over a storage period of 4 months (de Cássia da Fonseca *et al.,* 2009).

Types of oils employed as a dispersed phase also affected to physicochemical properties, concomitantly stability, of salad dressing (Nor Hayati *et al.,* 2007; Protonotariou *et al.,* 2013). Chemical composition and physical property of the used oils influenced size of dispersed drops produced from homogenization process. Variations in type of oils altered viscosity ratio between disperse and continuous phases, which further affected to a minimum size of oil drops produced under a steady state condition (McClements, 1999). Lower oil volume separation and smaller sized oil droplet diameter of the dressing could be observed when olive oil was employed as a dispersed phase than did sesame oil (Protonotariou *et al*., 2013). This behavior was postulated since a greater consistency of pseudoplastic behavior of olive oil than did sesame oil (Akhtar *et al*., 2009). Dissimilar pseudoplasticity of vegetable oils affected to emulsification ability, *i.e.,* drop breakdown, consequently droplet size and product stability (Protonotariou *et al*., 2013). Regarding composited fatty acids, it has been suggested that medium-chain triacylglecerides (TAGs) provided emulsion with greater stability than the system containing long-chain TAGs (Driscoll *et al*., 2001). The best stability of the emulsions made by the oils with lowest unsaturatation degree was also confirmed in the study of Granger *et al*., (2005). By replacing soybean oil with palm kernel oil, the oil consisted mainly of saturated fatty acids with the content of *ca*. 71 %, at the levels of 10–30 %, the emulsion with a good stability could be prepared as

suggested by no drop aggregation through a period of 1 month (Nor Hayati *et al.,* 2007). By decreasing in unsaturation degree, oil drops tended to form a stronger network that affected to retard drop mobilization in the emulsified matrix, thereby lowering drop aggregation (Nor Hayati *et al.,* 2007). A significant presence of C6:0 to C12:0 in palm kernel oil, moreover, was believed to partly contribute to a structural rearrangement and thus allowed better miscibility between dispersed and continuous phases during dressing preparation (Nor Hayati *et al.,* 2007).

With higher polarity compared to long chain TAGs, medium chain TAGs tended to orientate themselves towards an aqueous phase and interacted with adsorbed protein, thereby facilitating in a reduction of interfacial tension (Chanamai *et al*., 2002; Nor Hayati *et al*., 2007). It should be noted that that the lower the interfacial tension between oil and aqueous phases, the less physicochemical stress and easier dispersed drop formation (Driscoll *et al*., 2001). Granger *et al*., (2003) found that sunflower emulsion containing refined CO (more saturated) had a lower interfacial tension compared to those containing refined palm oil (less saturated). Beside this, other ingredients used to prepare dressings, *e.g.,* salt and acids, also had influence on characteristic of dressing product. With a presence of NaCl, droplet size tended to create a cluster without coalescence leading to alter flow behavior of the dressings (Protonotariou *et al.,* 2013).

Nowadays, not only good physical stability but also nutritive food products are appreciable for consumers. Lipid oxidation is an important chemical deterioration affecting to lower quality and nutritional value of salad dressing. By using vegetables oils containing saturated fatty acids and active biological compounds, stable dressings against lipid oxidation could be produced. Olive and sesame oils with a presence of high antioxidants and good fatty acids could be employed to prepare nutritive salad dressings (Protonotariou *et al*., 2013). It is well recognized that unsaturated fatty acids are prone to lipid oxidation (Bracco *et al*., 1981; Melton *et al*., 1994; Abdulkarim *et al*., 2007; Casal *et al*., 2010; Alireza *et al*., 2010; Marmesat *et al*., 2012). Considering on emulsion system where large interfacial areas between oil and aqueous phases are present, interactions between lipids and water

soluble pro-oxidants could be facilitated, leading to enhance lipid oxidation (Waroho *et al*., 2011). Reducing in unsaturation degree of the used oils, therefore, was one of the strategies to retard oxidative deterioration. Previous studies have shown that decreasing in unsaturated fatty acid content could improve overall properties (Driscoll *et al*., 2001), as well as oxidative stability (Nor Hayati *et al*., 2005) of emulsion models.

3.6 Tapioca maltodextrins (TMD)

Tapioca starch is obtained from roots of cassava plant, which is found in equatorial regions between the tropics of Cancer and Capricorn (William *et al.,* 2009). Tapioca is a shrubby perennial crop which is ease of plantation and low input requirement. It can grow in all soil types, but root formation is better in loose structured soils, such as light sandy loams and/or loamy sands. It can grow even in infertile soil or acid soil. Typical mature roots (9–12 months old) have an average composition of 60–70 % water, 30–35 % carbohydrate, 1–2 % fat, 1–2 % fiber, and 1–2 % protein with a trace quantity of vitamins and minerals (Rojanaridpiched, 1989). Mature roots possess starch content from 15–33 % depending on the climate and harvest time.

Tapioca starch is differentiated from other starches by its low level of residual materials (especially for proteins and lipids), lower amylose content, and high molecular weights of amylose and amylopectin (Swinkels, 1985). Typically, cassava starch contains 17–20 % amylose, whereas corn and rice consist of 0–70 % and 0–40 % amylose contents, respectively. The amylose molecules of cassava starch are not completely unbranched as indicated by lower β-amylolysis limit than those observed for corn, potato, rice and wheat starches. In addition, cassava amylose has a higher molecular weight than other starches (Rojanaridpiched, 1989). The low amylose, lipid and protein contents combining with high molecular weight of amylose make tapioca is a unique native starch for food and industrial application. Application of tapioca starch primarily involves enzyme catalyzed hydrolysis providing various products by varying enzyme types, degree of hydrolysis and derivatization. Important products obtained by direct hydrolysis of starch are sugar syrups, *i.e.,* glucose– and maltose syrups (Shahidi and Han, 1993). The syrups produced from tapioca starch are

bland taste, clean flavor, high purity and ease of cooking due to a lower gelatinization temperature.

Maltodextrin is a hydrolysis product of starch consisting of α-(1,4) linked D-glucose oligomers and/or polymers. Generally maltodextrin is produced through acid, enzyme, or acid/enzyme combination hydrolysis process (Shahidi and Han, 1993). Maltodextrin can be classified based on average molecular dextrose equivalent (DE), which is the index indicating reducing power of starch derived polysaccharide/oligosaccharides compared with D-glucose on a dry weight basis (Wang and Wang, 2000). Normally, maltodextrin has a DE value less than 20 (Shahidi and Han, 1993). Maltodextrin with different DE values exhibited different physicochemical properties, *e.g.,* solubility, freezing temperature, and viscosity (Dokic *et al.,* 2004). Maltodextrin with a same DE also possessed different properties depending on the hydrolysis procedure, source of starch, and amylose to amylopectin ratio (Dokic *et al.,* 2004). Maltodextrin is widely employed as a stabilizer, as well as a texture modifier to improve stability of emulsified product (Dokic *et al.,* 2004; Hardas *et al.,* 2000; Hogan *et al*., 2001). Maltodextrin predominantly played role on emulsion stability by modifying viscosity or gelation of a continuous phase of the system (Dickinson, 2003). Emulsions containing maltodextrin as a stabilizer always require an additional emulsifying agent (Hogan *et al.,* 2001). For emulsion containing surfactant and polysaccharide, stability of the system depends on interaction between surfactant and polysaccharide at both interface area and aqueous phase (Dickinson, 2003). Small molecular surfactants could bind to maltodextrin by inserting their non-polar tails into a helical coil of maltodextrin chain, resulting in alteration of functionality of both the surfactant and maltodextrin in emulsion system (Wangsakan *et al.,* 2001, 2003). Molecular characteristics of maltodextrin, such as concentration and chain length, could affect rheology and stability of emulsion. Source of starch is one of crucial factors influencing the properties of MD, because starches from various botanicals have dissimilarity in chain-length distribution and molecular weight. Considering on utilization of maltodextrin on stability of dressing product, Klinkesorn *et al*. (2004) reported that the dressing containing the corn maltodextrin with DE of 36, 25, 20, 15 and 10 begun to

flocculate, when the maltodextrin concentrations were 35, 21, 21, 17 and 13 % (w/w), respectively. Regarding TMD, it has been reported that critical flocculation concentration (CFC) of TMD with DE 9, 12 and 16 was 5.5, 7, and 11 (w/w), respectively (Udomrati *et al.,* 2013). At a concentration lower than CFC, TMD was suggested to be an effective rheological modifier that might be useful to improve salad dressing stability. Coalescence of the system could be inhibited by incorporating TMD with DE of 12 (9) at the concentration of 40 (35) %, whereas creaming was thoroughly observed over the concentration range of 15–50 % (w/w) when TMD with DE 16 was used (Udomrati *et al.,* 2013).

3.7 Deep frying and improvement on oil stability via oil blending technique

Deep frying, conducted by immersing foods in hot oil to maintain all flavors and juices within a crispy crust, is one of the most popular culinary processes both for industrial and domestic food preparation. The quality of fried foods depends not only on a frying condition (*e.g.*, temperature, replenish of fresh oil, frying time, and food weight), but also on a type of used oils, frying materials, antioxidants and oxygen concentration (Romero *et al*., 2006; Alireza *et al*., 2010). Oil is generally used as a medium in frying, where it is exposed to elevated temperature (*ca*. 150–180 °C) with a presence of oxygen and water. This extreme condition affected to accelerate series of chemical reactions, including hydrolysis, oxidation, polymerization, isomerization, and cyclization (Romero *et al*., 2006; Alireza *et al*., 2010). The series of chemical reactions involve in formation of volatile and non-volatile compounds that affected to decay oil qualities in functional, sensorial, and nutritional aspects, especially when frying was conducted repeatedly (Romero *et al*., 2006; Casal *et al*., 2010; Wang *et al*., 2013). Peroxides, free fatty acids, oxidized fatty acids, polymeric substances, and various polar compounds, *e.g.,* alcohol, aldehydes, ketones, and partial glycerides, were the degraded products emerging during frying (Srivastava and Semwal, 2015). For small molecular compounds, they could easily volatile and escape from a system, thereby creating off-flavor in fried food products (Gutierrez *et al*., 1988; Melton *et al*., 1994). Polymerization of unsaturated carbonyl and non-polar compounds, *e.g*., hydroperoxides, conjugated dienoic acids, ketones, and hydroxides, could be dissolved in oil, resulting in

darkening and increasing in viscosity of the oils (Gutierrez *et al*., 1988; Yaghmur *et al*., 2001). Impaired quality of frying oil was also evident by a decreasing in heat capacity and surface/interface tension, as well as gaining in specific gravity, viscosity, acid value, and polymer content (Blumenthal and Stier, 1991). Due to thermal process, moreover, nutritional value of medium oils was inferior, regarded due to a lowering in unsaturated fatty acids (USFAs) content and loss of other bioactive compouds (Bracco *et al*., 1981; Melton *et al*., 1994; Abdulkarim *et al*., 2007; Farhoosh *et al*., 2009; Alireza *et al*., 2010; Casal *et al*., 2010; Marmesat *et al*., 2012). Vitamin E content, originally present in vegetable oils at a concentration of 15–49 mg α-tocopherol equivalent/100 g, was lost along with oxidation of unsaturated fatty acids during heating process (Andrikopoulos *et al.,* 2003; Ghidurus *et al.,* 2010). Upon frying, minor components, *e.g*., sterol and organic acids were also eliminated (Gómez-Alonso *et al.,* 2003). Srivastava and Semwal (2015) suggested that oxidation of polyphenol compounds during continuous heating led to significantly decrease in polyphenol content of VCO, resulting in inferior antioxidant efficiency of the oil. Casal *et al.,* (2010) observed more pronounced degradation degree of tocopherol and tocotrienol in olive oil when heating time was increased: These compounds decomposed sharply after 3–6 h of frying, especially for α-tocopherol. Significant diminishing in tocopherol content (16.6–76 %) was also reported in soybean and sunflower oils (Juárez *et al*., 2011). Fast degradation of phenolic compounds was supposed due to high frying temperature (Gómez-Alonso *et al.,* 2003; Juárez *et al*., 2011). Gómez-Alonso *et al., (*2003) found suffered phenolic content in olive oil with an increase in number of frying operation with varying tendencies: Decreasing of tyrosol and its derivatives was much smaller than that observed for hydroxytyrosol family when the oil was repeatedly used for french-fries preparing. Lowered degradation of tyrosol compared to hydroxytyrosol was also reported in the study of Brenes *et al*., (1999): Twenty percentage of tyrosol diminishing was observed, whereas hydroxytyrosol degraded more than 95 % after frying for 12 cycles. High levels of oxidized polar compounds in frying oils affected to impair nutritional quality of fried foods (Gordon and Kourimská, 1995). Moreover, some polar compounds isolated from oxidized oil were toxic for laboratory animals (Alireza

et al., 2010; Pantzaris, 1998; Lamboni and Perkins, 1996). Note that the frying oil containing more than 24–27 % total polar content (TPC) is recommended to be discarded (Firestone, 1993).

Oils with richness in polyunsaturated fatty acids (PUFAs) are always recognized as nutritive oil, because of their ability to reduce cholesterol in blood stream which might be beneficial to prohibit some chronic diseases, *e.g*., cardiovascular disease (Reena and Lokesh, 2007). In deep frying process, however, it has been suggested that the more unsaturated the oil the greater susceptibility to degradation (Bracco *et al*., 1981; Melton *et al*., 1994; Abdulkarim *et al*., 2007; Casal *et al*., 2010; Alireza *et al*., 2010; Marmesat *et al*., 2012). During frying process, the highest and lowest degradation rates of composited fatty acids of canola oil were found for C18:3 and C18:1, respectively (Alireza *et al*., 2010). Tynek *et al*., (2001) reported a relative loss of C18:2 of oil after frying. Wang *et al*., (2013) also observed a significantly diminishing in C18:2 and C18:3 of SBO after frying. Upon frying, destruction of C=C through oxidation and polymerization as suggested by a diminishing of iodine value was reported in various oils, *e.g.,* canola (Normand *et al.,* 2006; Alireza *et al*., 2010; Farhoosh *et al*., 2009), sunflower (Normand *et al.,* 2001; Pangloli *et al*., 2002; Juárez *et al*., 2011; Marmesat *et al.,* 2012), SBO (Juárez *et al.,* 2011), and corn oils (Naz *et al.,* 2005; Sunisa *et al*., 2011; Ramadan and Wahdan, 2012). Due to frying, the amount of saturated fatty acids might be increased. Alireza *et al*., (2010) observed an increment of C16:0 and C18:0 for RBD palm and canola oils, and expected since a transform of double and triple bonds in unsaturated fatty acids into the counterparts with the same or shorter of carbon chain. Romero *et al*., (2006) suggested that the oils with low in C18:2 and high in C18:1 tended to be oxidized more readily than the oils with higher in C18:2 and lower in C18:1, which had a greater tendency to undergo polymerization. Moreover, it was evident that formation of polymer in thermal exposed oil increased with degree of oil unsaturation (Marmesat *et al.,* 2012).

Reduction in unsaturation degree of oils could be a promising way to improve oil stability against oxidation and degradation during deep frying process (Marmesat *et al.,* 2012). Good frying stability of palm olein (Alireza *et al*., 2010) and olive (Velasco and Dobarganes,

2002; Gómez-Alonso *et al.,* 2003) oils was postulated due to their less contents in PUFAs. Partial hydrogenation is a common way used to decrease PUFAs content in vegetable oils (Alireza *et al*., 2010). Nonetheless, negative nutritional implications of partial hydrogenated oils were approved (Marmesat *et al*., 2012). Using oils with a good resistance against oxidation, *i.e*., oils with lower in PUFAs content, to blend with vegetable oils could be a practical strategy to enhance thermal stability of oils (Alireza *et al*., 2010; Chu and Kung, 1998). Frying stability of canola oil could be successfully improved by blending with RBD palm oil (Alireza *et al*., 2010). Development in thermal stability of canola oil could also be accomplished by diminishing PUFAs content via blending with some selected oils: The frying time resulting in TPC higher than 24 % was extended from 7.3 h to 15.97, 13.7, and 8.2 h when canola oil was blended with palm olein, olive, and corn oil, respectively (Farhoosh *et al*., 2009). By blending with palm olein, moreover, oxidation resistance of canola oil along deep frying process could significantly improve (Farhoosh *et al*., 2009). It should be noted that even though oil degradation was expected to be accelerated by increasing in unsaturation degree of the used oils, dissimilar tendencies could be found in different oils (Normand *et al*., 2001, 2006; Smith *et al*., 2007; Warner and Fehr, 2008).

Degraded products emerged from frying process were accumulated in the oils and then be incorporated into foods, thereby lowering food qualities (Gordon and Kourimská, 1995; Pangloli *et al*., 2002; Juárez *et al.*, 2011). Upon frying in the oil with higher oxidative degree, volatile and peroxide substances accumulated in the oils were transferred to foods, resulting in undesirable flavor of the fried foods (Pangloli *et al*., 2002). Potato chips fried in the sunflower oil blended with 40 % of palm olein showed a good stability against lipid oxidation along a storage period of 4–6 weeks (Pangloli *et al*., 2002). Suppressed lipid oxidation degree in the blended oil led to higher sensory evaluation score of the fried products: The quality score was decreased with increasing level of C18:3 in frying oil. Improvement of oxidative stability of oils during frying, therefore, is a practical way to produce fried foods with desirable quality and safety.

Soybean oil (SBO) is an all purpose cooking-oil widely used in Thailand. Regarding to its high content of PUFAs, *ca*. up to 65 %, SBO is susceptible to lipid oxidation and thermal degradation during deep frying process (Anwar *et al.,* 2007; Nor Hayati *et al.,* 2007). After frying at 180 °C for 15 h, dramatically increase in polar materials of SBO from 4.5 to 28.5 % that was higher than the mandatory discard level of frying oil (Andrikopoulos *et al.,* 2003; Firestone, 1996) was reported (Juárez *et al.,* 2011). Gil *et al*., (2004) also reported low stability of SBO against frying process.

To improve thermal stability of PUFAs rich oils, blending technique using saturated oils has been implemented. Better frying stability of coconut oil compared to sunflower, soybean, and palm oils was reported, which was expected since lower level of PUFAs content and higher in endogenous polyphenolic compounds of coconut oil (Marina *et al*., 2009a). Some indigenous compounds, *e.g.,* tocopherols, sterols, hydrocarbons, carotenoids, polyphenols, and trace metals, in oils could enhance their stability against oxidation and decomposition during frying (Gómez-Alonso *et al.,* 2003; Casal *et al*., 2010; Karakaya and Simsek, 2010; Juárez *et al*., 2011). By simultaneous incorporation of these bioactive compounds to the processed foods, nutritive value of the products could be improved (Casal *et al.,* 2010). Frying stability of canola oil was successfully improved by blending with sesame oil, postulated due to a presence of endogenous phenolic compounds (Alireza *et al*., 2010). Konsoula and Liakopoulou-Kyriakides (2010) reported a reduction in DPPH scavenging capacity of olive oil with increasing of frying time, but this decreasing could be lowered by adding sesamol: The time used to reduce 50 % of DPPH activity of the oil was increased from 15 to 19 h when 900 μL of sesamol was applied.

4. Research Methodology

4.1 Study on oil recovery efficiency and characteristics of virgin coconut oil (VCO) derived by different oil extraction techniques

4.1.1 Preparation of coconut milk

VCO was extracted from a fully mature coconut (*Cocos nucifera* L.) with the age of 10–11 months old as indicated by a yellowish to brown husk color appearance and a sloshing

sound when shaken. Firstly, the coconut milk was separated using a screw press (Fujica CM-SJ, Bangkok, Thailand). The grafted coconut meats were pressed for three times and separated milk was pooled together and thoroughly mixing for a few minutes. To separate the oil, the coconut milk was destabilized using different methods.

4.1.2 Oil separation from coconut milk

The extracted coconut milk was destabilized to liberate oil using different techniques.

4.1.2.1 Fermentation

The coconut milk was incubated at a controlled temperature of 30 ± 2 °C (water bath, Binder BD115, Tuttlingen, Germany) for 24, 36 and 48 h. The sample was then centrifuged (Beckman Coulter Avanti JE, California, USA) at 15,000×*g* for 15 min to separate coconut cream and aqueous phase. To obtain clear oil, the cream phase was further centrifuged at 15,000×*g* for 15 min. This procedure was modified from the method of Raghavendra and Raghavarao (2010).

4.1.2.2 Thermal cycling

The coconut milk was subjected to freeze-thaw program with various numbers of cycle, according to the method described by Raghavendra and Raghavarao (2010) with some modifications. Initially, the coconut milk was freezed at -20 °C for 6 h, placed at room temperature for 30 min, and heated at 60 °C for 10 min in a water bath. This tempering program included 7 h and defined as 1 cycle. The coconut milk was treated for 1–4 cycles, before centrifuging at 15,000×*g* for 15 min. The separated cream phase was further centrifuged at 15,000×*g* for 15 min to release clear oil.

4.1.2.3 Enzyme assisted extraction

In this process, Alcalase which is the protease from *Bacillus licheniformis* with the activity of ≥ 5U/g (1 U corresponds to the amount of enzyme which set free 1 μmol folin-positive amino acids and peptide (as tyrosine) per minute at pH 7.0 and 37 °C using casein as substrate) was used. The enzyme was introduced to the coconut milk at different concentrations (0.05, 0.1 and 0.3%, w/w), and oil extraction was conducted at 60 °C for various times (0, 15, 30, 60 and 120 min). The sample was then centrifuged at 15,000×*g* for

15 min, and the cream phase was further centrifuged at 15,000×*g* for 15 min to release clear oil. This procedure was modified from Raghavendra and Raghavarao (2010).

4.1.3 Determination of oil recovery yield, physical properties and chemical compositions of the derived oils

4.1.3.1 Determination of oil recovery efficiency

Oil recovery efficiency was determined by the following equation (Mansor *et al.,* 2012).

$$\%\,\text{oil recovery} = \frac{((\text{weight of extracted oil}/\text{weight of coconut milk}) \times 100)}{(\%\,\text{oil in coconut milk})} \times 100$$

4.1.3.2 Determination of saponification value (SV)

SV measurement was carried out according to the method of IUPAC (1992). The oil (2 g) was mixed with KOH solution in ethanol (0.5 N, 25 ml), before distilling for 1 h. After cooling to room temperature, the mixture was titrated with HCl (0.5 N) using phenolphthalein as an indicator.

4.1.3.3 Determination of iodine value (IV)

IV was determined by a standard method of IUPAC (1992). The oil (1 g) was thoroughly mixed with cyclohexane (15 ml) and Wijs solution consisting of iodine monochloride (0.5 % v/v, 25 ml), before incubating in the dark for 1 h. After adding with KI solution (10 % w/v, 20 ml) and water (150 ml), the mixture was titrated with a standard solution of sodium thiosulfate (0.1 N) using a starch solution as an indicator.

4.1.3.4 Determination of free fatty acid (FFA)

FFA was determined by a titration method (IUPAC, 1992). The oil (8 g) was mixed with ethanol (50 ml), before neutralizing with NaOH (0.01 N) using phenolphthalein as an indicator. FFA of the oil samples was expressed as a percentage of lauric acid.

4.1.3.5 Determination of peroxide value (PV)

PV was quantified by the standard method of IUPAC (1992). The oil sample (5 g) was thoroughly mixed with a mixture of acetic acid:chloroform (3:2 v/v, 25 ml) and saturated KI solution (1 ml), before incubating in the dark for 1 h. After adding water (75 ml), the mixture

was titrated with a standard solution of sodium thiosulfate (0.01 N) using a starch solution as an indicator.

4.1.3.6 Quantification of total phenolic content (TPC)

TPC present in the oil sample was determined by Folin-Ciocalteu assay as per the method of Arslan *et al.* (2013) with a slight modification. Briefly, the oil (5 g) was mixed with a mixture of ethanol:water (80:20 v/v, 3 ml), before centrifuging at 5000×*g* for 5 min. This extraction was carried out for three times and all ethanolic extracts were combined, before evaporating until dryness using a rotary evaporator (Eyela N-1000, Tokyo, Japan). The dry matter was redispersed using a mixture of methanol:water (10:90 v/v, 1 ml), before adding with water (8.2 ml) and Folin-Ciocalteau reagent (0.5 ml). The mixture was allowed to stand at room temperature for 5 min, added with sodium carbonate solution (10 % w/v, 1 ml), and incubated at room temperature for 60 min. The absorbance at 765 nm was then read (UV-Vis Spectrophotometer, UV-1700, Shimadzu, Kyoto, Japan). TPC was calculated using a standard curve of gallic acid (0–100 µg/100 ml) and expressed as milligrams gallic acid equivalents (GAE) per kilogram of oil.

4.1.3.7 Determination of phenolic composition

Firstly, phenolics were extracted from the VCO followed the method described by Arslan *et al.* (2013). Briefly, the oil (5 g) was mixed with a mixture of ethanol:water (80:20 v/v, 3 ml), before centrifuging at 5000×*g* for 5 min. This extraction was carried out for three times and all ethanolic extracts were combined, before evaporating until dryness using a rotary evaporator. The dry matter was redispersed using a mixture of methanol:water (10:90 v/v, 1 ml). Phenolic compounds present in the oil were identified by HPLC (Agilent Technologies 1200 series G1329A, Waldbronn, Germany), the column was a Hypersil ODS (250 mm×5 µm) with 4 mm packing (Thermo Electron Corporation, Waldbronn, Germany). The flow rate was 0.85 ml/min and the injection volume 20 µL. The total run time was 35 min. The eluents were 2 % aqueous acetic acid solution (A) and methanol (B). The gradient time program was set as follow: 0 min 5 % B, 3 min 15 % B, 13 min 20 % B, 25 min 25 % B, and 32 min 30 % B. The absorbance at 240, 280, and 320 nm was read. Identification of each

phenolic was determined based on a combination of retention time, using catechin, gallic, *trans*-ferulic, vanillic, *p*-coumaric, and syringic acids as standards.

4.1.3.8 Determination of fatty acid composition

Fatty acid composition of the oil samples was examined according to the method of Chowdhury *et al.* (2007). The oil (50 μl) was added with KOH solution (0.5 N in methanol, 1 ml) and digested by stirring in a boiling water bath for 20 min. After cooling to room temperature, the sample was added with a mixture of HCl:methanol (4:1 v/v, 0.4 ml), deionized water (2 ml) and petroleum ether (3 ml). The distinct upper layer of methyl ester was then separated carefully and dried by nitrogen gas. The sample was redispersed using chloroform (1 ml), before introducing to GC (Agilent technologies 7890A, Wilmington, USA) equipped with a flame ionization detector. Varian's capillary column (VF-5 ms, 30 m×0.25 mm×0.25 μm; EZ-GRIP^{TM}, Wilmington USA) was employed. The column was conditioned at 180 °C for 2 h to attain thermal stability before use. The temperature condition was operated as following: Holding at oven temperature of 150 °C for 5 min, increasing to 190 °C with a rate of 8 °C/min, increasing to 200 °C with a rate of 2 °C, and holding at 200 °C for 10 min. Injection and detection temperatures were 250 °C. Nitrogen was used as a carrier gas with a flow rate of 20 ml/min.

4.2 Study on physicochemical stability of salad dressings made from different kinds of oils as affected by tapioca maltodextrin (TMD) adding

Salad dressings were prepared employing VCO and SBO as a dispersed phase. To optimize product formulation, effect of TMD was adding on physicochemical stability of the dressing samples was studied by varying dextrose equivalent (DE), *i.e.,* DE 9, 12, and 16, and concentrations, *i.e.,* 0, 0.5, 1.5, and 3 %, w/w.

4.2.1 Salad dressing preparation

The dressing was produced in a laboratory scale at a total weight of 500 g, as per the method of Ma *et al.,* (2013). Firstly, a premix was prepared using vinegar (18 %), egg yolk (6 %), sugar (23 %), salt (1.8 %), mustard (3 %), potassium-sorbate (0.1 %), and TMD at different concentrations (0.5, 1.5 and 3 %). The oil phase (48 %) was added drop wise to the aqueous

phase. Blending was performed using a blender (Tefal BL1161AD, Jakarta, Indonesia) for 4 min at room temperature. The dressings were transferred into a glass bottle and stored in a condition similar to those in a convenience store, by placing in a shelf unit at ambient temperature with illumination for 12 h/day. Three batches of the dressings were prepared separately. The dressing samples were kept for 2 months and subjected to analyses.

4.2.2 Physical characteristics of the dressings

4.2.2.1 Oil droplet size: Mean diameters of oil drops were measured using a laser diffraction particle size analyzer (Brookhaven Instruments Ltd, Holtsville, New York). The volume mean diameter, $d_{4,3} = \sum n_i d_i^4 / \sum n_i d_i^3$, where n_i is the number of droplets of the diameter of d_i, was reported.

4.2.2.2 Creaming index (CI): The dressing (10 g) was transferred to a test tube tightly sealed with a plastic cap, before centrifugation at 7,690×*g* for 25 min. CI was calculated as follows;

$$CI(\%) = \left(H_C / H_T\right) \times 100$$

where H_C and H_T are the height of the cream layer and the total height of emulsion, respectively (Sun and Gunasekaran, 2009).

4.2.2.3 Color measurement: Color of the dressing samples was measured using a colorimeter (Hunter Lab ColorFlex, Hunter Associates Laboratory, Virginia, USA). A fixed amount of dressing was poured into a measuring cup, surrounded with a black paper strip. Color parameters including *L** representing lightness to darkness (0=black and 100=white), *a** exhibiting redness (+) to greenness (-), and *b** indicating yellowness (+) to blueness (-) were measured. Total change in color (ΔE) with storage time was calculated using the following equations (Ma *et al.,* 2013):

$$\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

where ΔL^*, Δa^*, Δb^* are the difference on *L**, *a**, and *b** value at the initial time and at time t, respectively.

4.2.3 Chemical characteristics of the dressings

4.2.3.1 Determination of pH: The dressing sample (1 g) was mixed with DI water (10 ml), before measuring pH using a pH meter (FEP20, Mettier-Toiedo AG, Schwerzenbach, Switzerland) as per the method of Adebayo *et al.,* (2010).

4.2.3.2 Determination of TPC: The dressing sample (8 g) was mixed with acidified acetone consisted of 70 % acetone and 0.1 % HCl at a ratio of 4:1 (v/v) (15 ml). The mixture was then allowed to stand at room temperate for overnight, before filtering through filter paper. The supernatant (10 ml) was concentrated using a rotary vacuum evaporator (Eyela N-1000, Tokyo, Japan) at 45 °C until dryness. The dry matter was redispersed using a mixture of methanol:water (10:90 v/v, 1 ml), before adding with water (8.2 ml) and Folin-Ciocalteau reagent (0.5 ml). The mixture was allowed to stand at room temperatures for 5 min, before reacting with sodium carbonate solution (10 % w/v, 1 ml). After incubating for 60 min at room temperature, the absorbance at 765 nm was read. TPC was calculated using a standard curve of gallic acid (0–100 µg/100 ml) and expressed as mg gallic acid equivalents (GAE) per kilogram of sample (Tseng and Zhao, 2013).

The dressing samples were transferred to amber bottles and kept at 50±2 °C for 8 weeks in the dark. Progressive of lipid oxidation was periodically monitored by measuring PV, the content of thiobarbituric acid reactive substances (TBA) and *para*-anisidine value (*p*-AnV).

4.2.3.3 PV determination: The dressing (0.6 g) was mixed with a mixture of isooctane:propanol (3:1 v/v, 3 ml), before centrifugation at 1,950×*g* for 2 min. A clear upper layer (200 µl) was taken out to react with a mixture of methanol:1-butanol (2:1 v/v, 2.8 ml), ammonium thiocyanate (3.97 M, 15 µL), and ferrous iron solution (15 µL) containing an equal volume of 0.132 M $BaCl_2$ and 0.144 M $FeSO_4.7H_2O$. After incubation at room temperature for 20 min, the absorbance at 510 nm was determined. PV was quantified using a standard curve of cumene hydroperoxide (0–250 mg/kg sample) and expressed as mg hydroperoxide equivalent/kg sample (Shantha and Decker, 1994).

4.2.3.4 TBA determination: The dressing (10 g) was mixed with distilled water (97.5 ml), 4 N HCl (2.5 ml) and antifoaming. The mixture was distillated, and the received volume of 50 ml

was transferred to react with 2-thiobarbituric acid (TBA) reagent consisted of 0.28 % TBA in 90 % acetic acid (5 ml). The mixture was heated in boiling water at 100 °C for 35 min, and cooled in an ice bath for 10 min. The absorbance at 532 nm was then read. The content of TBA was quantified using a standard curve of malondialdehyde (0–100 mg/kg sample) and expressed as mg malondialdehyde equivalent/kg sample (Rossell, 1994).

4.2.3.5 p-AnV determination: Briefly, the dressing sample (2 g) was added into a 25 ml volumetric flask and made up to volume with isooctane. After mixing thoroughly, the sample was transferred to a 50 ml centrifuge tube and vortexed twice for 10 s each. After centrifugation at 5,000 rpm for 10 min, absorbance (A_1) of the upper layer was measured at 350 nm against isooctane as a blank. The upper layer (5 ml) was then transferred to a 10 ml test tube, and added with *p*-An solution (0.25 % in glacial acetic acid, 1 ml). After incubation at room temperature for 10 min, absorbance (A_2) was measured at 350 nm against isooctane containing *p*-AnV as a blank. *p*-AnV was determined using the equation (Enríquez-Fernández *et al.*, 2011):

$$p-AnV = \frac{25 \times (1.2 \times (A_2 - A_1))}{2}$$

4.2.4 Rheological property of the dressings

Rheological measurement was performed using a rheometer (Haake RS75, TA Instrument, New Castle, DE, USA) equipped with a stainless steel parallel plate (3.5 cm diameter) with a gap setting of 1 mm. Dynamic oscillatory, steady state flow, and creep and recovery tests were performed. The measurement temperature was controlled at 25 °C using a circulation bath and a controlled Peltier system. One tablespoon of sample was placed at a center of the plate, and excess sample was removed from the edges of the plate. After reach to a steady state, a power-law model flow test was performed based on a raw data fitting, according to the equation;

$$\eta = k\,\gamma^{(n-1)}$$

where *k* is consistency coefficient, γ is the shear rate (s^{-1}), *n* is flow behavior index, and η is the viscosity (Pa.s) (Bortnowska *et al.,* 2014).

4.2.5 Sensory Evaluation of the dressings

Sensory analysis was carried out in a sensory laboratory. The dressing (10 g) was placed on a white plastic glass labeled with a three-digit code and served to a panelist with green oak, carrot, and cone (10 g) in a random order. The evaluation was performed by 40 panelists. The attributes and sensory descriptions involving appearance, color, odor, viscosity, taste and overall likeness were evaluated using 9-points hedonic scale, with 1 being dislike extremely and 9 being like extremely (Mihov *et al.,* 2012). Each attribute has its own individual scale.

4.3 Improvement on frying stability of soybean oil (SBO) via blending technique with coconut oil (CO)

The commercial SBO was blended with CO at various ratios, *i.e.,* the volume ratio of SBO:CO were 100:0 (control), 80:20, 60:40, and 50:50. The blended oil samples were then employed to cook French-fries and chicken nuggets at various repeated frying cycles. Physicochemical changes for both the oils and fried foods were observed.

4.3.1 Oil blending

SBO was blended with VCO at the designated volume ratio by mixing with the overhead stirrer equipped with a propeller (RW 20.n, IKA Labortechnik, Staufen, Germany) at a speed of 100 rpm for 15 min. Each oil blend was divided into 3 parts for used separately in each replication. The blended oils were kept in plastic bucket, flushed with nitrogen, and kept at 4 °C for no longer than 2 month. Prior to use, the blended oil was stored at room temperature for overnight and mixed to ensure homogeneity. Fatty acid composition of the oil samples was investigated by gas chromatography following the procedure of Chowdhury *et al.* (2007).

4.3.2 Frying experiment

To observe frying stability of the blended oils, different food commodities, involving French-fries and chicken nugget as the representative of carbohydrate– and protein based foods, respectively, were used.

4.3.2.1 Frying of French-fries: Potatoes with the size *ca.* 20–30 tubers/kilogram were washed under running tap water, before peeling. French-fries stripes ($0.8 \times 1.0 \times 4.5$ cm^3) were prepared, washed with running tap water to remove starchy, and dried with a paper towel.

For the frying protocol, 2 L of oil sample was filled into an electrical fryer and pre-heated at 175 °C for 10 min to equilibrate temperature. Then, 55–60 g of the French-fries (*ca*. 10–12 pieces) were fried at 175 °C for 3 min and drained in a frying basket for 1 min. Twenty batches were fried each day constituting 1 frying cycle. After finishing an each cycle, the oil was allowed to cool down overnight. Some amount of oil was replenished to maintain the initial volume oil, before beginning frying in each cycle. Five cycles were conducted for each blended oil sample. This frying plan was adapted from the study of Enríquez-Fernández *et al.*, (2011).

4.3.2.2 Frying of chicken nuggets: Chicken nuggets were prepared using chicken breast meat, which was deboned, trimmed of external fat, and partially ground by a food processor. Na_3PO_4 (0.35 %) and NaCl (0.5 %) were mixed in water (3.0 %) and added to the ground meat. Ground skin (3.5 %) and seasonings (1.65 %) were added to the previously mixed meat. Then, the whole part was thoroughly ground. The batter (20 g) was then shaped using a circular mould (2 cm diameter). This procedure was modified from Jackson *et al.,* (2006).

For the frying protocol, 2 L of oil sample was filled into an electrical fryer and pre-heated at 175 °C for 10 min to equilibrate temperature. Then, 3 pieces of the nuggets were fried at 175 °C for 3 min and drained in a frying basket for 1 min. Twenty batches were fried each day constituting 1 frying cycle. After finishing an each cycle, the oil was allowed to cool down overnight. Some amount of oil was replenished to maintain the initial oil volume, before beginning frying in each cycle. Five cycles were conducted for each blended oil sample. This frying plan was adapted from the study of Enríquez-Fernández *et al.*, (2011).

4.3.3 Oil analysis

After the frying for 1, 3, and 5 cycles, the oils were taken, filtered into a screw cap bottle, flushed with nitrogen, and promptly stored in the dark at -20 °C for further analyses.

4.3.3.1 Color: through the Hunter parameters of *L* (lightness), *a* (variation green to red), and *b* (variation blue to yellow) according the method of Enríquez-Fernández *et al.*, (2011)

4.3.3.2 Investigation on thermal properties: using differential scanning calorimeter (DSC), according to the method of Tan *et al*., (2001)

4.3.3.3 Fatty acid composition: by GC as per the method of Chowdhury *et al.* (2007) as described in the part 4.1.3.8

4.3.3.4 Determination of iodine value (IV): by a standard method of IUPAC (1992) as described in the part 4.1.3.3

4.3.3.5 Determination of free fatty acid (FFA): by a titration method (IUPAC, 1992) as described in the part 4.1.3.4

4.3.3.6 Determination of peroxide value (PV): by the standard method of IUPAC (1992) as described in the part 4.1.3.5

4.3.3.7 Determination of p-AnV: by the standard method of AOCS (1990). Briefly, the accurately weighted oil was dissolved in isooctane (25 ml), before measuring the absorbance at 350 nm (A_1). The mixture was then mixed with p-anisidine reagent (0.5 % in acetic acid) and allowed to stand at room temperature for 10 min, before reading the absorbance at 350 nm (A_2). The *p-AnV* was quantified by the following equation;

$$p - AnV = \frac{25 \times (1.2 \times (A_2 - A_1))}{W}$$

where W is the weight of oil sample. This protocol was described by Lee *et al.,* (2007).

4.3.3.8 Quantification of total polar matters (TPM): using the food-oil monitoring apparatus (Erbo electronic FOM 310, Germany)

4.3.4 Fried product analysis

The cooked French-fries and nuggets from 1st, 3rd, and 5th frying cycles were collected, dried on a paper towel for about 2 min, kept in a plastic container, and stored at -20 ℃ for analyses. The food samples fried in fresh oils were used as a control.

4.3.4.1 Moisture content: by the standard method (AOAC, 1995)

4.3.4.2 Fat content: through the standard method using hexane as a solvent (AOAC, 1995)

4.3.4.3 Crust color: using the Hunter scale of *L** (lightness), *a** (variation green to red), and *b** (variation blue to yellow) according the method of Enríquez-Fernández *et al.*, (2011)

4.3.4.4 Texture profile analysis: Textural characteristic of the fried foods was observed using a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK). For the French-fries, the samples at the 15^{th}–16^{th} batches of the selected cycle were taken to measure hardness (N/cm^2; maximum force required to attain a given deformation) and fracturability (the force with the sample fracture and signifies a product of high hardness and low cohesiveness) (Bourne, 2002). Regarding to the chicken nuggets, the samples at the 15^{th}–16^{th} batches of the selected cycle were compressed using a compression probe. Hardness (N/cm^2; maximum force required to compress the sample), cohesiveness (extent to which sample could be deformprior to rupture), and chewiness (N/cm; work to masticate the sample or swallowing) (Das *et al*., 2008).

4.4 Statistical analysis

Experiments were conducted in triplicate and the results were expressed as mean values ± std. Comparison between means was carried out using two-way analysis of variance (ANOVA). Differences between means were estimated by Duncan multiple range test by the SPSS statistic program (Version 10.0; SPSS Inc., Chicago, IL, USA) at a confident level of 95 %.

5. Results and Discussion

5.1 *Study on oil recovery efficiency and characteristics of virgin coconut oil (VCO) derived by different oil extraction techniques*

5.1.1 Oil recovery efficiency

To prepare VCO, the meat of fully mature coconut fruits was firstly separated, and the coconut milk was then prepared. Table 1 illustrates chemical compositions of the coconut meat and milk.

Main components of the coconut meat and coconut milk were moisture and fat with the contents of *ca.* 57 (63) % and 28 (30) % for coconut meat (coconut milk), respectively. These values were agreed well with the study of Popper *et al.,* (1966), reporting the moisture and fat contents of *ca*. 54.1 % and 32.2 %.

Table 3 Chemical compositions of the coconut meat and milk

Chemical compositions	Coconut meat (% w/w wet basis)	Coconut milk (% w/w wet basis)
Moisture	56.56±0.40	62.71±0.35
Protein	3.50±0.13	2.41±0.03
Fat	27.67±0.10	30.37±0.32
Ash	1.08±0.40	0.60±0.02

After that oil liberation from the coconut milk was carried out through traditional methods, *i.e*., fermentation and thermal cycling techniques, and enzyme-aided means. Oil recovery efficacy and physicochemical properties of the VCO derived by different techniques were then investigated. Oil recovery yields provided by conventional methods of fermentation and thermal cycling techniques were shown in **Figure 1**. By using fermentation means, the extraction yield could be improved to 74.9 % by prolonging fermentation time up to 36 h ($p<0.05$), whereas extended incubation time for 48 h had no further improvement effect on oil recovery yield ($p>0.05$). Satheesh and Prasad (2014) reported that coconut oil could be released after fermentation time of 24–48 h. Upon fermentation, oil releasing from the coconut milk emulsion matrix could be accomplished by gravitational force (Raghavendra and Raghavarao, 2010) and activity of airborne lactic acid bacteria (Srivastava and Semwell, 2015). Lactic acid bacteria used lactose present in the coconut milk and produced lactic acid, leading to alter acidity of the system to around pH 4 that coconut proteins were easily coagulated (Tangsuphoom and Coupland, 2008). It has been suggested that coconut milk emulsion was destabilized by adjusting pH of the coconut milk emulsion to the range of 3–5.6 (Marina *et al*., 2009a).

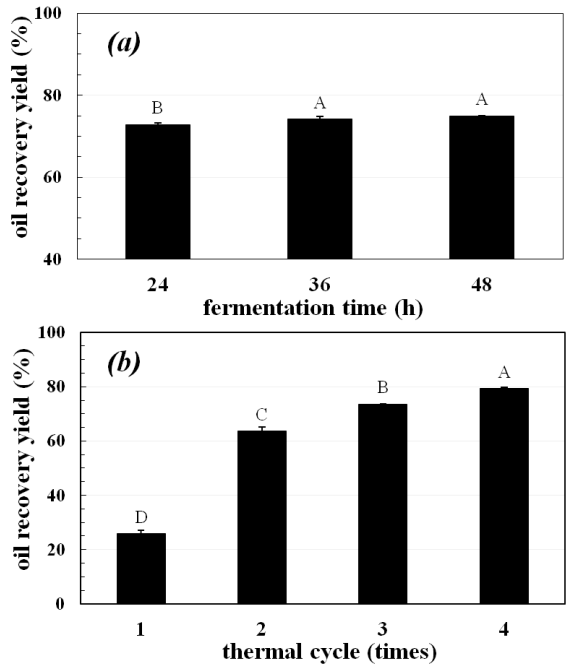

Figure 1 Oil recovery yield provided by ***(a)*** fermentation technique at different incubation times and ***(b)*** thermal cycling technique at various numbers of cycle

Means with standard deviations (n=3) were shown. In each subfigure, different letters indicate significant difference between means (p<0.05).

Oil recovery yields provided by thermal cycling means were illustrated in **Figure 1b**. Increase a number of freeze-thaw cycle could enhance oil liberation, and the highest yield of 79.0 % was found after treating the coconut milk for 4 cycles (28 h of total incubation time) (p<0.05). As a result of temperature lowering, oil drops in coconut milk were solidified. Further thawing affected to deform a spherical shape of oil droplets, thereby promoting coalescence of dispersed oil droplets and leading to a releasing of oil phase from the emulsified matrix (Marina *et al.,* 2009b; Raghavendra and Raghavarao, 2010). Reduce temperature in a chilling step could improve oil recovery yield: The extraction yields of *ca*. 65, 74, and 92 % were found for VCO production, after chilling the coconut milk at 20, 15, and 5 °C for 6 h, respectively (Raghavendra and Raghavarao, 2010).

Oil recovery efficiency derived by the enzyme aided extraction was observed at various enzyme concentrations and incubation times, and the result was illustrated in **Figure 2**. Increase enzyme concentration affected to improve oil recovery yield, especially when incubation time was increased. The highest yield of 93.5 % could be obtained by using the

protease at the level of 0.3 % and incubation time of 120 min (p<0.05). Further increase enzyme concentration and incubation time had no effect on oil recovery efficiency (p>0.05) (*data not shown*). The coconut milk emulsion was partially stabilized by the coconut proteins (Seow and Gwee, 1997; Tangsuphoom and Coupland, 2008), so protease could enhance demulsification by hydrolyzing interior peptide bonds of the protein residues, resulting in shorten protein/peptides structures with inferior emulsifying property (Meroth *et al.,* 2003). The fractured proteins/peptide chains tended to move towards aqueous phase, thereby facilitating oil liberation from the coconut milk emulsion (Rosenthal *et al.,* 1996). Moreover, proteolytic enzymes could enhance disruption of cytoplasmic network by degrading protein molecules covering around oil bodies, thereby promoting oil separation from plant cells (Rosenthal *et al.,* 1996; Jiang *et al.,* 2010). Yoon *et al.* (1991) reported that using proteolytic enzymes could improve yield for soybean oil extraction, which resulted in a final yield of 86 % compared to 62 % in the process carried out without enzymes. In the case of rapeseed, an extraction oil yield of 78 % was obtained using protease aided extraction (Lanzani *et al.,* 1975).

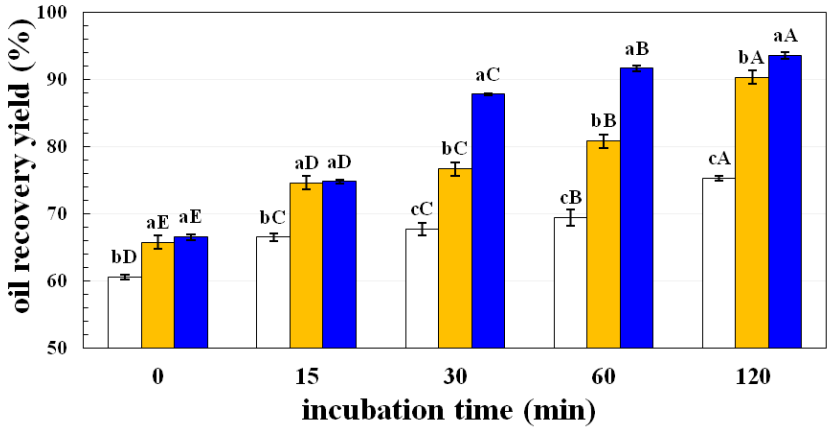

Figure 2 Oil recovery yield provided by protease aided extraction at different enzyme concentrations, *i.e,* 0.05 (□), 0.1 (■), and 0.3 % w/w (■), and incubation times.

Means with standard deviations (n=3) were shown. Different small (capital) letters in the same incubation time (protease concentration) indicate significant difference between means (p<0.05).

Comparing to the traditional methods, *i.e.,* fermentation and thermal cycling techniques, the protease aided extraction could provide higher oil recovery yield. From the

present result, the highest oil extraction yields derived by fermentation (48 h), thermal cycling (4 cycles of total time of 28 h), and enzyme aided (0.3 % enzyme concentration and extraction time of 120 min) methods were 74.9 %, 79.0 %, and 93.5 %, respectively. To more elucidate the effects of different oil recovering methods on properties of VCO, some selected properties of the VCOs prepared by the conditions providing the highest recovery yields in each studied technique were further examined comparing with the commercial VCO.

5.1.2 Characterization of VCO

Fatty acid compositions of the VCO samples were examined (see **Table 4)**. The properties of commercial VCO and the Asian pacific coconut community standards (APCC, 2003) were also illustrated in order for comparison.

The major fatty acid residues in all VCO samples were medium chain fatty acids (MCFAs), *i.e.,* C12:0 and C14:0. This result was in accordance with the previous works (Chowdhury *et al*., 2007; Raghavendra and Raghavarao, 2010). By using different extraction techniques, a slight difference in fatty acid compositions of the VCOs was evident. As comparing to the VCO produced by enzyme aided extraction, the VCO recovered by traditional techniques contained less amount of unsaturated fatty acids, *i.e.,* monounsaturated fatty acids (MUFAs) of C18:1 and polyunsaturated fatty acids (PUFAs) of C18:2 for the oils recovered by thermal cycling and fermentation techniques, respectively ($P<0.05$). These tendencies are in agreement with the reported of Marina *et al.,* (2009a). Regarding to a well-recognized health benefit of unsaturated fatty acids (Reena and Lokesh, 2007), the present result implied a better nutritive value of the VCO recovered by protease assisted process than the counterparts derived by the traditional techniques. Superior nutritional value of the VCO prepared by the aid of aspartic protease compared to the commercial VCO were suggested by the higher amounts of short chain fatty acids, *i.e.,* C8:0 and C10:0 (Raghavendra and Raghavarao, 2010). In the present work, fatty acid compositions of the VCOs recovered by different techniques and the commercial VCO were within the standard values of APCC.

Table 4 Fatty acid compositions (% total fatty acids, TFAs) of the VCOs produced from different methods

Fatty acid (% TFAs)	Extraction method			Commercial	APCC standard
	fermentation	thermal cycling	enzyme aid		
C8:0	6.69±0.31^{a}	5.93±0.12^{ab}	5.81±0.71^{b}	6.69±0.21^{a}	5.00–10.00
C10:0	6.86±0.41^{a}	6.48±0.16^{a}	7.16±0.61^{a}	7.10±0.20^{a}	4.50–8.00
C12:0	49.51±1.21^{b}	51.72±1.14^{a}	50.44±0.50^{ab}	50.10±0.94^{ab}	43.00–53.00
C14:0	18.28±0.48^{a}	17.80±0.26^{ab}	17.63±0.50^{ab}	17.24±0.26^{b}	16.00–21.00
C16:0	8.88±0.38^{a}	8.19±0.48^{b}	8.02±0.08^{b}	8.37±0.23^{ab}	7.50–10.00
C18:0	2.87±0.09^{a}	2.71±0.10^{ab}	2.84±0.19^{a}	2.56±0.15^{b}	2.00–4.00
C18:1	5.92±0.18^{ab}	5.16±0.87^{b}	6.29±0.30^{a}	5.77±0.15^{ab}	5.00–10.00
C18:2	1.00±0.30^{b}	1.53±0.38^{a}	1.87±0.18^{a}	1.91±0.07^{a}	1.00–2.50
Σsaturated fatty acids	91.87±0.42^{b}	93.08±0.11^{a}	92.85±0.86^{ab}	92.07±0.73^{b}	
Σunsaturated fatty acids	8.16±0.24^{a}	6.92±0.11^{ab}	6.68±0.87^{b}	6.84±0.15^{ab}	

Mean values ± standard deviations (n=3) were shown.

Letters within a same row indicate significant difference between means (p<0.05).

Next, some selected characteristics of the VCOs produced by various techniques and the commercial VCO were examined as present in **Table 5.** The VCO prepared by enzyme aided means had the lowest PV and FFA contents compared to oils prepared by other techniques ($p<0.05$), suggesting to its better initial quality. Fermentation methods resulted in the highest FFA of the VCO compared to the enzymatic and thermal cycling methods. This might be expected due to a prolonged processing time that might effect to induce hydrolysis reaction, thereby increasing FFA (Satheesh and Prasad, 2014). However, the FFA of all VCOs produced in this work conferred to the APCC standard. Note that the VCO recovered through thermal cycling, enzymatic and fermentation methods reported by Mansor *et al*. (2012) contained the higher FFA (0.29–0.35 mg KOH/g) than the present work. The highest SV was found for the VCO extracted by thermal cycling means ($p<0.05$). The highest IV could be observed for the oils recovered by enzyme aided means ($p<0.05$), which was coincident with its higher content of unsaturated fatty acids as illustrated in **Table 4**. The moisture content of VCOs recovered by different techniques was comparable ($p>0.05$) within the range of 0.15 %, except for commercial VCO showing the lowest moisture content ($p<0.05$). Moisture content is one of the important factors determining shelf-life of the product, higher moisture content faster degree of chemical deterioration (Che Man *et al.,* 1996; Marina *et al*., 2009a). Higher total phenolic content (TPC) was observed for the oil prepared by fermentation technique ($p<0.05$), implying to a greater nutritive value of the oil. Through fermentation process, pH of the coconut milk was reduced to acidic range that might affect to hydrolyze bound phenolics, resulting in higher TPC content of the derived oil (Baublis *et al.*, 2000). This acidic condition. When the phenolic composition of the VCO prepared via fermentation technique was observed (see **Figure 3**), it was found that catechin, gallic, vanillic, and *p*-coumaric acids were predominant. This was in correspondence with the report of Seneviratne *et al.* (2008). The unidentified signals in the HPLC profile were supposed to be oxidized and/or bound forms of phenolic compounds (Seneviratne *et al.,* 2009; Arslan *et al.,* 2013).

Table 5 Characteristics of the VCOs produced from different methods

Characteristics	Extraction method			Commercial	APCC Standard
	fermentation	thermal cycling	enzyme aid		
PV (milli Equiv. O_2/kg fat)	0.78±0.08^{a}	0.66±0.03^{ab}	0.53±0.14^{b}	0.72±0.05^{a}	Max 3
FFA (% lauric acid)	0.15±0.01^{b}	0.10±0.01^{c}	0.12±0.01^{c}	0.20±0.02^{a}	Max 0.2
SV (mg KOH/g fat)	262.77±4.66^{b}	271.72±3.35^{a}	269.23±2.85^{ab}	269.05±1.61^{ab}	250–260 Min
IV (g I_2/100g fat)	7.26±0.13^{b}	7.01±0.08^{c}	7.62±0.14^{a}	7.36±0.04^{a}	4.1–11
Moisture content (%)	0.15±0.001^{a}	0.15±0.001^{a}	0.15±0.001^{a}	0.12±0.001^{b}	Max 0.1
TPC (mg GAE/kg)	59.30±0.39^{a}	29.71±0.01^{d}	35.02±0.10^{c}	43.59±0.52^{b}	-

Mean values ± standard deviations (n=3) were shown.

Letters within a same row indicate significant difference between means (p<0.05).

The Asian Pacific Coconut Community (APCC) standards were shown in order for comparison (APCC, 2003).

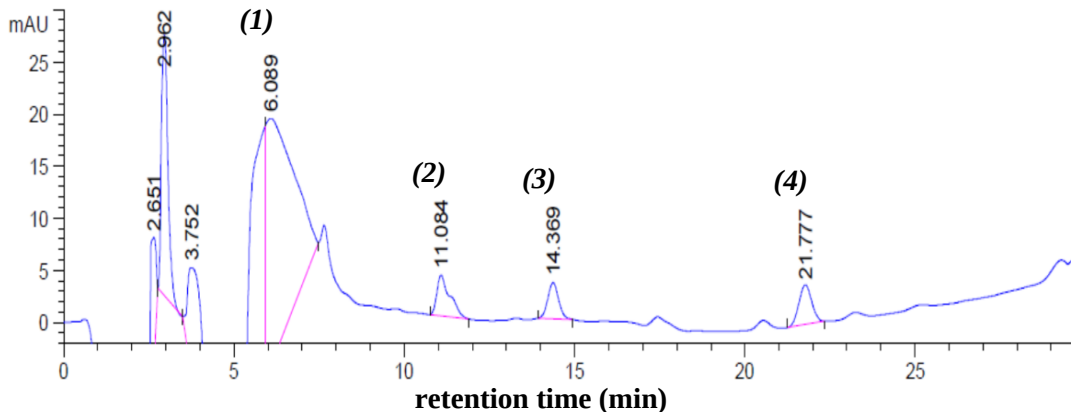

Figure 3 HPLC chromatogram of the phenolic fraction of the VCO derived by fermentation method: ***(1)*** gallic acid, ***(2)*** catechin, ***(3)*** vanillic acid, and ***(4)*** *p*-coumaric acid

Considering on the VCO recovered by fermentation technique, the higher amount of TPC was observed. Nonetheless, a fermented off-odor could be obviously detected for the VCO recovered through fermentation means, whereas protease aided means provided the oil with pleasant natural coconut odor. It was suggested that a fermented odor affected to mask a natural desirable flavor of coconut oil and might reduce consumer acceptability (Koh and Long, 2012). Better initial quality of the lowered PV and FFA, and higher nutritive value of more abundantly present unsaturated fatty acids were found for the VCO recovered by protease aided means compared to those produced by fermentation technique. Additionally, based on economic view, the protease aided extraction could effectively enhance oil extraction yield with less production time. Therefore, extraction using protease was selected to prepare VCO in a further study. Nonetheless, it should be noted that all of the observed parameters of the VCOs were within the limits of APCC standard, suggesting that the VCOs produced in the present work could be employed commercially.

5.2 Study on physicochemical stability of salad dressings made from different kinds of oils as affected by tapioca maltodextrin (TMD) adding

Salad dressings were prepared employing VCO as a dispersed phase, and their physicochemical stability was investigated, in comparison with the counterparts made from soybean oil (SBO). Moreover, effects of tapioca maltodextrin (TMD) adding on properties of

the dressing samples were studied, by varying dextrose equivalents (DE: *i.e.,* DE of 9, 12, and 16) and concentrations (*i.e.,* 0.5, 1.5, and 3 %) of TMD.

5.2.1 Physical characteristics

To determine colloidal stability of the dressings, initial oil droplet size of the dressing samples incorporated with TMD was firstly evaluated, and the result was depicted in **Figure 4**. The initial emulsion sizes of all dressings were within the range of *ca*. 2.0 to 2.75 μm. By using VCO, the dressings with smaller droplet size compared to the SBO counterparts could be observed. This might be attributed to a different characteristic of the used oils. The predominant fatty acids of VCO are MCFAs, especially for lauric and myristic acids, whereas SBO mainly consists of long chain fatty acids, especially for linoleic acid (Chowdhury *et al.,* 2007). Greater hydrophobicity of SBO might cause a higher tension at the oil-water interfaces, resulting in bigger produced oil drops (Driscoll *et al.,* 2001). Moreover, it has been suggested that a bigger initial drop size was tended to be observed when the oils with higher viscosity was used, because more intense disruption force was needed to deform oil drops during emulsification process. Note that the viscosities of SBO and coconut oil were reported as 31.8 and 28 cP, respectively (Noureddini *et al.,* 1992). TMD incorporation at different generally concentrations had no significant effect on the initial d_{43} of the dressings (p>0.05), irrespective of DE levels. Klinkesorn *et al*. (2004) reported that there was no difference on drop diameter of the corn oil emulsions containing corn maltodextrin at different concentrations (0–35 wt %). DE levels of TMD also had no effect on initial size of dispersed drops of the model soybean oil emulsions (Udomrati *et al.,* 2011).

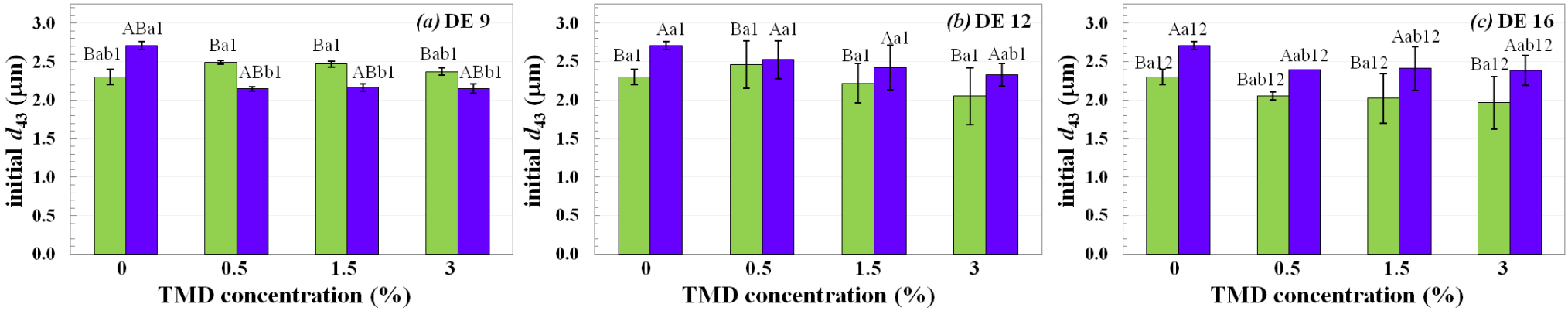

Figure 4 Initial droplet mean diameter (d_{43}) of the VCO (■) and SBO (■) dressings stabilized by TMD with **(*a*)** DE 9, **(*b*)** DE 12, and **(*c*)** DE 16 at various concentrations (0–3 %)

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same TMD concentration (p<0.05), and different lower letters indicate significant difference between means in a same oil type (p<0.05).

Different numeric letters indicate significant difference between means at a same TMD concentration and oil type (p<0.05).

To more elucidate colloidal stability, change in droplet size and creaming rate of the dressings were monitored as a function of storage times, as shown in **Figure 5** and **Figure 6**, respectively.

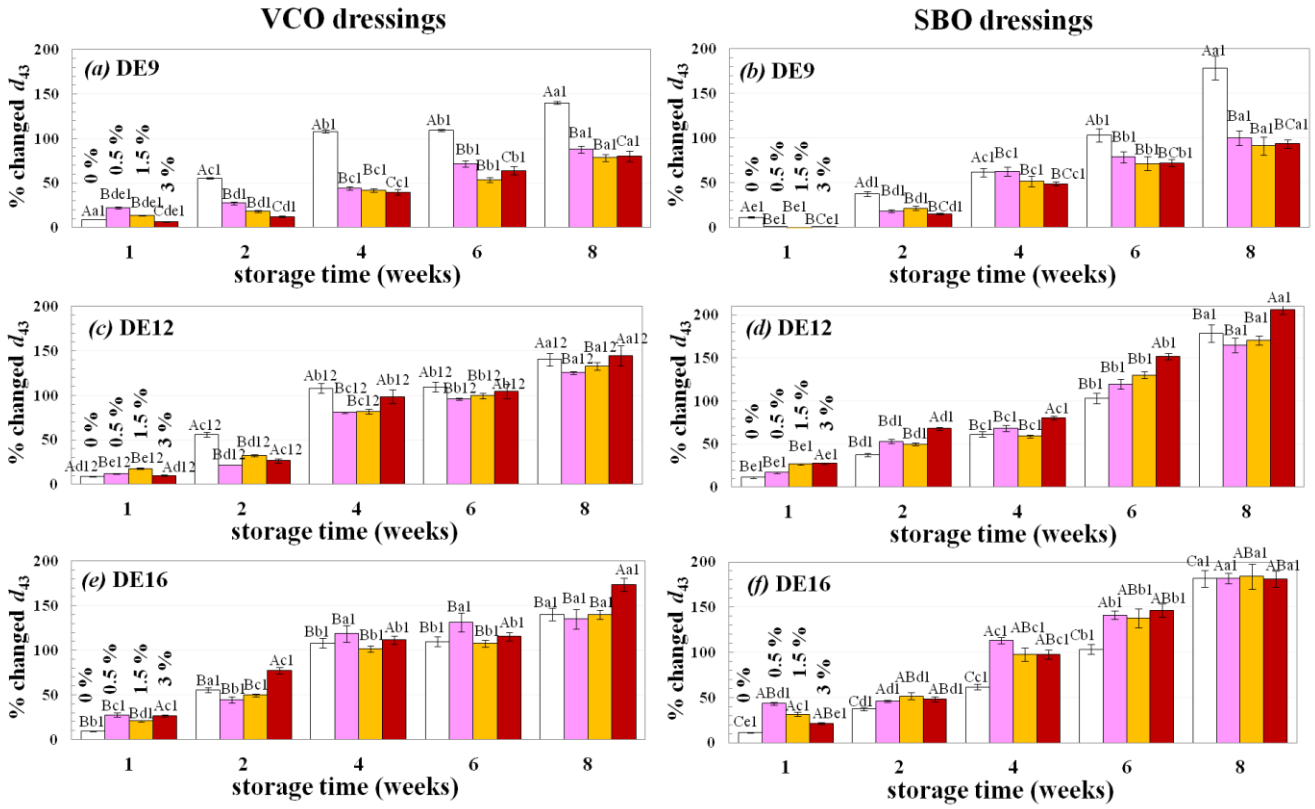

Figure 5 Percentage of changed d_{43} of the salad dressings at various storage times. The dressings were stabilized using TMD with ***(a, b)*** DE 9, ***(c, d)*** DE 12, and ***(e, f)*** DE 16. TMD was introduced to the dressings at 0 % (☐), 0.5 % (■), 1.5 % (■), and 3 % (■).

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time (p<0.05), and different lower letters indicate significant difference between means in a same TMD concentration (p<0.05).

In each DE value, different numeric letters indicate significant difference between means at a same concentration and DE of TMD (p<0.05).

By employing TMD with DE 9, increment on d_{43} with storage time of the dressings could be retarded more effectively than those observed for the dressings added with TMD with DE 12 and 16, regardless of oil types. With a suitable DE, or in turn molecular size, TMD

might function as a thickening agent to increase viscosity of the dressing appropriately, thereby delaying drop aggregation. Considering on the effects of oil type, smaller change in d_{43} could be observed for VCO dressing compared to those made from SBO: For the systems incorporated with TMD with DE 9, the droplet size changed significantly after storage for 1 week (2 weeks) for SBO (VCO) dressings (p<0.05), irrespectively of TMD concentrations. This tendency suggested to a better stability of VCO emulsion than did SBO counterparts.

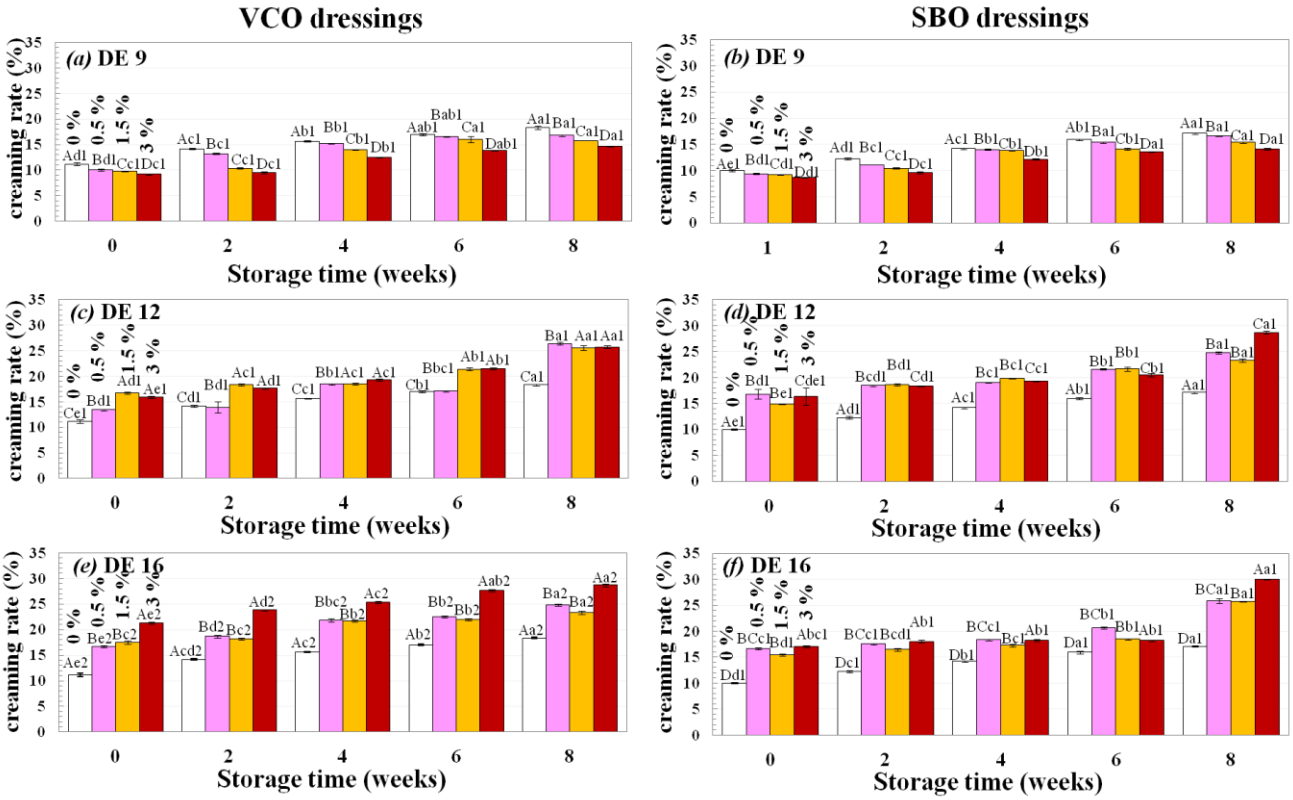

Figure 6 Creaming rate of the salad dressings at various storage times. The dressings were stabilized using TMD with ***(a, b)*** DE 9, ***(c, d)*** DE 12, and ***(e, f)*** DE16. TMD was introduced to the dressings at 0 % (☐), 0.5 % (■), 1.5 % (■), and 3 % (■).

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time (p<0.05), and different lower letters indicate significant difference between means in a same TMD concentration (p<0.05).

In each DE value, numeric letters indicate significant difference between means at a same concentration and DE of TMD (p<0.05).

Along 8 weeks of storage, the dressings added with TMD DE 9 showed obviously lowered creaming rate compared to the control and samples incorporated with TMD at DE 12 and 16. For the samples added with TMD at DE 9, increasing TMD concentration could thoroughly decrease creaming rate of the dressings ($p<0.05$). Nonetheless, adding TMD at DE 12 and DE 16 led to higher creaming rate compared to the control sample ($p<0.05$). This result suggested to the ability of TMD with DE 9 to maintain colloidal stability of the dressings, which was in agreement with long term drop dispersibility, as previously suggested in **Figure 5**. Maltodextrins could induce a formation of three dimensional gel network, attributed to the interactions between a helical region of amylose fractions and linear chains of amylopectin molecules (Chronakis, 1998), thereby delaying phase separation in emulsified matrix (Klinkesorn *et al.,* 2004; Udomrati *et al.,* 2011). For the VCO and SBO dressings incorporated with TMD at DE 9, the lowest creaming was found when the TMD was added at 3 %, whereas difference in creaming rate of the VCO dressings and the SBO counterparts was not noticeable ($p>0.05$). However, it should be noticed that the creaming rate of the VCO (SBO) dressings with the presence of TMD DE 9 at the concentration of 1.5 and 3 % increased significantly after 2 weeks (1 week) of storage.

Physical characteristics of the dressing were further determined by measuring pH and as a function of storage time. **Table 6** shows time dependence on pH of the VCO and SBO dressings containing TMD at different DEs and concentrations. All of the dressing samples had a comparable pH value within an acidic range of 3.52 to 3.66. Acidity plays important role to protect biological deterioration of a dressing product (Richard, 1977). In this work, TMD had no effect on pH of the samples ($p>0.05$), suggesting that TMD could be employed as a stabilizer in the product.

Table 6 Storage time dependence on pH of the VCO and SBO dressings containing TMD at different DE (9, 12, and 16) and concentrations (0–3 %)

oil phase	TMD		Storage time (weeks)						
	DE	content (%)	0	1	2	3	4	6	8
VCO	Control	0	3.55±0.01	3.60±0.01	3.52±0.01	3.61±0.01	3.62±0.01	3.57±0.01	3.61±0.01
	9	0.5	3.57±0.01	3.57±0.01	3.53±0.01	3.63±0.01	3.57±0.01	3.61±0.01	3.63±0.01
		1.5	3.57±0.01	3.58±0.01	3.55±0.01	3.64±0.01	3.57±0.01	3.63±0.01	3.63±0.01
		3	3.60±0.01	3.60±0.01	3.60±0.01	3.64±0.01	3.58±0.01	3.64±0.01	3.65±0.01
	12	0.5	3.56±0.01	3.57±0.01	3.58±0.01	3.60±0.01	3.62±0.01	3.61±0.01	3.63±0.01
		1.5	3.61±0.01	3.60±0.01	3.59±0.01	3.62±0.01	3.61±0.01	3.63±0.01	3.63±0.01
		3	3.61±0.01	3.62±0.01	3.60±0.01	3.64±0.01	3.62±0.01	3.64±0.01	3.65±0.01
	16	0.5	3.56±0.01	3.56±0.01	3.55±0.01	3.60±0.01	3.62±0.01	3.59±0.01	3.62±0.01
		1.5	3.57±0.01	3.60±0.01	3.58±0.01	3.66±0.01	3.65±0.01	3.62±0.01	3.62±0.01
		3	3.61±0.01	3.60±0.01	3.58±0.01	3.64±0.01	3.62±0.01	3.61±0.01	3.61±0.01
SBO	Control	0	3.53±0.01	3.57±0.01	3.55±0.01	3.58±0.01	3.58±0.01	3.59±0.01	3.59±0.01
	9	0.5	3.53±0.01	3.56±0.01	3.55±0.01	3.59±0.01	3.57±0.01	3.56±0.01	3.57±0.01
		1.5	3.54±0.01	3.56±0.01	3.57±0.01	3.58±0.01	3.53±0.01	3.53±0.01	3.57±0.01
		3	3.55±0.01	3.57±0.01	3.56±0.01	3.62±0.01	3.56±0.01	3.54±0.01	3.55±0.01
	12	0.5	3.57±0.01	3.60±0.01	3.60±0.01	3.60±0.01	3.60±0.01	3.60±0.01	3.59±0.01
		1.5	3.57±0.01	3.64±0.01	3.65±0.01	3.63±0.01	3.62±0.01	3.61±0.01	3.61±0.01
		3	3.57±0.01	3.62±0.01	3.64±0.01	3.64±0.01	3.63±0.01	3.62±0.01	3.61±0.01
	16	0.5	3.62±0.01	3.60±0.01	3.64±0.01	3.63±0.01	3.63±0.01	3.62±0.01	3.61±0.01
		1.5	3.54±0.01	3.63±0.01	3.66±0.01	3.64±0.01	3.61±0.01	3.62±0.01	3.60±0.01
		3	3.52±0.01	3.64±0.01	3.66±0.01	3.64±0.01	3.62±0.01	3.63±0.01	3.62±0.01

Means with standard deviations (n=3) were shown. There was no difference between means (p>0.05).

Color parameter, including lightness (*L**), redness (*a**), and yellowness (*b**), of the freshly prepared dressings made from VCO and SBO was evaluated, and the result was shown in **Figure 7**.

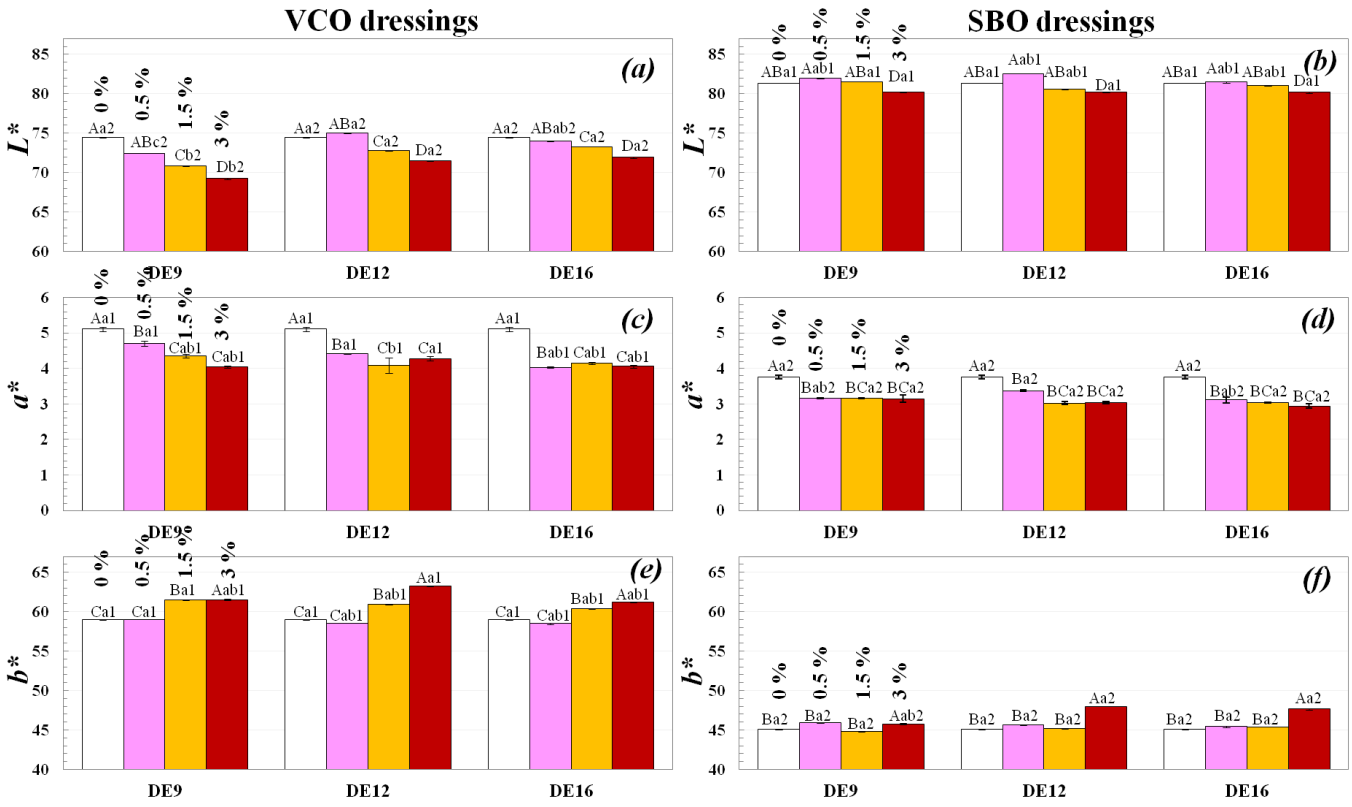

Figure 7 Color parameters including ***(a, b)*** *L**, ***(c, d)*** *a**, and ***(e, f)*** *b** of the freshly prepared salad dressings containing TMD at different DEs (9, 12, and 16). TMD was introduced to the dressings at 0 % (☐), 0.5 % (■), 1.5 % (■), and 3 % (■).

Means with standard deviations (*n*=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same DE ($p<0.05$), and different lower letters indicate significant difference between means in a same TMD concentration ($p<0.05$).

In each tested parameter, different numeric letters indicate significant difference between means at a same concentration and DE of TMD ($p<0.05$).

TMD adding affected to color of the dressings sample, as evident by a decreasing of *L** and *a**, as well as increasing of *b**. VCO dressings had obviously lowered score in lightness ($p<0.05$) and higher scores in redness ($p<0.05$) and yellowness ($p<0.05$) than the SBO

counterparts. These differences might be supposed since dissimilar in color of the used oil, as well as different in emulsion properties with different components. To more elucidate the color appearance of the dressings, change in color with storage time was monitored along a period of 8 weeks, and total change in color parameter (ΔE) of the samples was depicted in **Figure 8**.

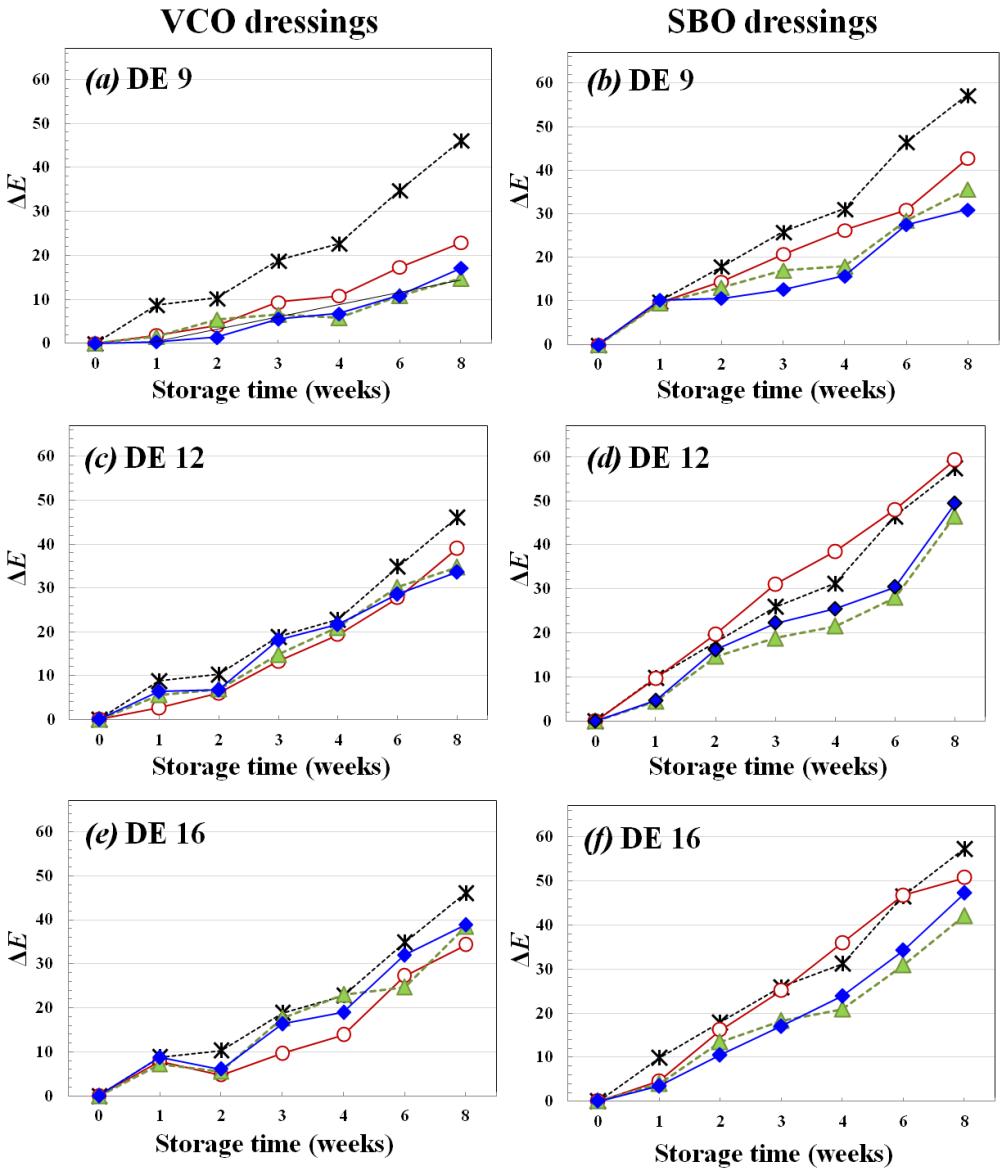

Figure 8 Storage time dependence on ΔE of the VCO and SBO dressings containing TMD with ***(a, b)*** DE 9, ***(c, d)*** DE12, and ***(e, f)*** DE 16 and various concentrations: 0 % (---∗---), 0.5 % (—○—), 1.5 % (---▲---), and 3 % (—◆—)

Upon storage, color of all dressings was altered, which might be supposed due to a proceeding of some chemical reactions, such as browning reaction that resulted in increasing of *a** value (Rein and Heinonen, 2004). As comparing to the control, adding TMD with DE 9 could lower ΔE for both VCO and SBO dressings over the observed time range (p<0.05). However, the dressings added with TMD DE 12 and 16 showed a comparable ΔE with the control (p>0.05). It should be noted that lowered change in color was also observed in mayonnaise and yogurt with a good stability (Tseng and Zhao, 2013). Lowered ΔE of TMD added dressings was more likely due to lowered change in droplet size of the emulsions as suggested by the previous result (see **Figure 5**). With different size, emulsified droplets might reflect light in different manners, thereby affecting to color of the products (Tseng and Zhao, 2013). It has been suggested that hydrocolloids could influence color stability of dressing product. With different chemical structures, hydrocolloids could interact with pigments and other ingredients present in the system dissimilarly, thereby altering color of the product (Hubbermann *et al.,* 2006). Lowered color retention capacity was observed for the dressings stabilized by locust bean gum, whereas corn starch, Na-alginate, and citrus pectin could maintain color of the product effectively (Hubbermann *et al*., 2006).Considering on the systems containing TMD with DE 9, ΔE was remarkably affected by oil type, in which the VCO dressings possessed lower ΔE than those of SBO counterparts, regardless of TMD concentration and storage time (p<0.05). This result indicated that the color of dressings could be maintained effectively by employing VCO as a dispersed phase.

Rheological properties of the VCO and SBO dressings were further evaluated. Consistency coefficient (k) and flow behavior index (n) were estimated using a power-law mathematical model (Izidoro *et al.,* 2009). To declare a fitting of flow curve of the samples with the predicting model, determination coefficient (R^2) was also shown. The *k, n,* and R^2 values of the VCO and SBO dressings observed over a storage period of 0–8 weeks were reported in **Table 7** and **Table 8**, respectively.

Table 7 Rheological behavior indices of the VCO dressings containing TMD at different DE (9, 12, and 16) and concentrations (0–3 %)

DE of TMD	storage time (weeks)	TMD concentration (%)											
		0			0.5			1.5			3		
		k	*n*	R^2	*k*	*n*	R^2	*k*	*n*	R^2	*k*	*n*	R^2
9	0	7.77±0.89	0.472±0.009	0.996±0.005	15.58±0.38	0.463±0.008	0.999±0.001	18.39±0.25	0.445±0.001	0.999±0.001	20.54±0.25	0.419±0.006	0.999±0.001
	1	8.53±0.33	0.475±0.016	0.999±0.001	14.72±1.41	0.478±0.015	0.999±0.001	17.80±0.16	0.453±0.003	0.999±0.001	18.97±0.27	0.444±0.004	0.998±0.001
	2	5.74±0.71	0.505±0.015	0.999±0.001	12.72±0.32	0.509±0.019	0.999±0.001	15.77±0.15	0.465±0.016	0.999±0.001	16.98±0.40	0.453±0.002	0.999±0.001
	3	4.55±0.89	0.522±0.021	0.999±0.001	11.20±0.13	0.522±0.006	0.999±0.001	14.11±0.80	0.467±0.005	0.999±0.001	16.58±0.08	0.454±0.002	0.999±0.001
	4	4.43±0.72	0.493±0.014	0.999±0.001	10.07±0.87	0.521±0.002	0.998±0.002	13.18±0.97	0.469±0.008	0.998±0.001	14.65±0.43	0.486±0.011	0.999±0.001
	6	4.32±0.25	0.563±0.019	0.999±0.001	8.96±0.47	0.544±0.021	0.999±0.001	12.01±0.90	0.504±0.004	0.999±0.001	12.88±0.44	0.508±0.008	0.999±0.001
	8	5.44±0.02	0.609±0.025	1.000±0.001	8.22±0.32	0.579±0.005	0.999±0.001	10.01±0.18	0.523±0.005	0.999±0.001	11.50±0.45	0.514±0.003	0.999±0.001
12	0	7.77±0.89	0.523±0.013	0.999±0.001	8.67±1.02	0.507±0.025	0.999±0.001	8.91±1.57	0.519±0.020	0.999±0.001	11.78±1.98	0.497±0.008	0.999±0.001
	1	8.53±0.33	0.508±0.023	0.999±0.001	8.54±0.59	0.521±0.011	0.999±0.001	9.82±0.96	0.531±0.018	0.999±0.001	10.57±0.76	0.543±0.014	0.999±0.001
	2	5.74±0.71	0.576±0.013	0.999±0.001	5.35±0.66	0.593±0.024	0.999±0.001	5.78±0.48	0.599±0.016	0.999±0.001	8.39±1.83	0.571±0.015	0.999±0.001
	3	4.55±0.89	0.603±0.008	0.998±0.002	4.90±1.61	0.604±0.029	0.999±0.001	7.91±0.65	0.571±0.014	1.000±0.001	8.78±0.76	0.583±0.013	0.999±0.001
	4	4.43±0.72	0.621±0.028	0.999±0.001	4.49±0.37	0.627±0.015	1.000±0.001	6.55±0.53	0.602±0.019	1.000±0.001	5.86±0.35	0.631±0.012	0.999±0.001
	6	4.32±0.25	0.627±0.018	1.000±0.001	3.37±0.17	0.652±0.003	0.999±0.001	4.97±0.06	0.638±0.009	1.000±0.001	6.01±0.29	0.634±0.007	1.000±0.001
	8	5.44±0.02	0.595±0.004	0.999±0.001	5.17±0.18	0.597±0.013	1.000±0.001	6.59±0.14	0.594±0.016	1.000±0.001	7.10±0.19	0.615±0.009	1.000±0.001

16	0	7.77±0.89	0.523±0.013	0.999±0.001	10.19±1.55	0.498±0.035	0.999±0.001	8.90±1.77	0.515±0.022	0.999±0.001	9.52±0.79	0.508±0.013	0.999±0.001
	1	8.53±0.33	0.508±0.023	0.999±0.001	8.26±1.89	0.522±0.056	0.998±0.003	7.02±0.35	0.562±0.005	0.999±0.001	7.87±1.28	0.557±0.020	0.999±0.001
	2	5.74±0.71	0.576±0.013	0.999±0.001	5.80±0.34	0.584±0.005	0.999±0.001	5.36±0.84	0.601±0.021	0.999±0.001	7.45±0.84	0.571±0.024	0.999±0.001
	3	4.55±0.89	0.603±0.008	0.998±0.002	6.20±0.64	0.581±0.015	0.999±0.001	7.36±0.19	0.571±0.009	1.000±0.001	7.43±0.39	0.575±0.006	1.000±0.001
	4	4.43±0.72	0.621±0.028	0.999±0.001	4.77±1.11	0.630±0.024	1.000±0.001	6.06±0.47	0.601±0.002	1.000±0.001	6.83±0.54	0.590±0.010	1.000±0.001
	6	4.32±0.25	0.627±0.018	1.000±0.001	4.66±0.83	0.616±0.006	0.998±0.002	4.83±1.23	0.623±0.045	0.999±0.001	5.54±0.24	0.615±0.006	1.000±0.001
	8	5.44±0.02	0.595±0.004	0.999±0.001	5.60±0.45	0.603±0.013	1.000±0.001	5.38±0.30	0.615±0.005	1.000±0.001	5.05±0.69	0.627±0.017	0.999±0.001

Means with standard deviations (*n*=3) were shown.

Table 8 Rheological behavior indices of the SBO dressings containing TMD at different DE (9, 12, and 16) and concentrations (0–3 %)

DE of TMD	storage time (weeks)	TMD concentration (%)											
		0			0.5			1.5			3		
		k	*n*	R^2	*k*	*n*	R^2	*k*	*n*	R^2	*k*	*n*	R^2
9	0	8.84±1.28	0.452±0.001	0.999±0.001	20.05±0.73	0.447±0.004	0.999±0.001	22.85±0.26	0.401±0.001	0.998±0.001	25.17±0.39	0.397±0.003	0.997±0.001
	1	7.95±0.33	0.469±0.008	0.999±0.001	18.42±0.10	0.435±0.004	0.999±0.001	22.12±1.28	0.427±0.006	0.999±0.001	23.55±0.29	0.403±0.001	0.999±0.001
	2	5.98±0.12	0.470±0.004	0.999±0.001	16.76±0.22	0.444±0.003	0.999±0.001	17.30±0.45	0.432±0.001	0.998±0.001	20.86±0.46	0.434±0.003	0.998±0.002
	3	4.90±1.27	0.506±0.003	0.999±0.001	13.79±0.44	0.463±0.003	0.999±0.001	14.97±0.98	0.451±0.008	0.999±0.001	17.39±0.50	0.447±0.003	1.000±0.001
	4	4.94±0.85	0.521±0.004	0.998±0.002	12.74±0.40	0.508±0.002	0.998±0.002	13.82±0.43	0.461±0.003	0.999±0.001	15.32±0.02	0.462±0.002	0.999±0.001
	6	5.53±0.43	0.538±0.015	0.999±0.001	10.15±0.16	0.525±0.004	0.999±0.001	12.33±0.38	0.505±0.004	1.000±0.001	13.74±0.25	0.495±0.004	0.999±0.001
	8	5.44±0.02	0.565±0.004	1.000±0.001	9.40±0.19	0.535±0.004	1.000±0.001	11.74±0.53	0.518±0.002	1.000±0.001	12.50±0.19	0.523±0.009	1.000±0.001
12	0	8.84±1.28	0.538±0.020	0.999±0.001	8.49±0.99	0.540±0.016	0.999±0.001	10.41±0.77	0.532±0.015	1.000±0.001	8.45±0.99	0.571±0.013	0.999±0.001
	1	7.95±0.33	0.563±0.017	0.999±0.001	7.07±2.01	0.585±0.033	0.999±0.001	9.90±0.32	0.542±0.007	1.000±0.001	9.08±0.22	0.580±0.001	1.000±0.001
	2	5.98±0.12	0.602±0.008	0.999±0.001	6.43±1.47	0.592±0.020	0.999±0.001	8.40±0.25	0.576±0.016	1.000±0.001	7.15±0.83	0.604±0.022	1.000±0.001
	3	4.90±1.27	0.617±0.022	1.000±0.001	6.15±0.93	0.604±0.025	1.000±0.001	7.03±0.30	0.600±0.014	1.000±0.001	6.52±0.35	0.621±0.014	1.000±0.001
	4	4.94±0.85	0.613±0.016	0.999±0.001	5.72±0.48	0.600±0.023	0.998±0.002	5.48±0.71	0.626±0.023	1.000±0.001	6.27±0.18	0.613±0.007	0.999±0.001
	6	5.53±0.43	0.604±0.019	1.000±0.001	5.36±0.58	0.619±0.013	0.999±0.001	6.90±1.02	0.602±0.020	1.000±0.001	7.58±0.32	0.596±0.006	1.000±0.001
	8	5.44±0.02	0.595±0.004	0.999±0.001	5.17±0.18	0.597±0.013	1.000±0.001	6.59±0.14	0.594±0.016	1.000±0.001	7.10±0.19	0.615±0.009	1.000±0.001

16	0	8.84±1.28	0.538±0.020	0.999±0.001	8.37±0.61	0.546±0.008	0.999±0.001	7.33±1.35	0.562±0.019	0.999±0.001	9.17±0.65	0.537±0.015	0.999±0.001
	1	7.95±0.33	0.563±0.017	0.999±0.001	7.73±0.93	0.573±0.016	1.000±0.001	7.49±1.10	0.583±0.014	0.999±0.001	7.98±0.32	0.585±0.006	1.000±0.001
	2	5.98±0.12	0.602±0.008	0.999±0.001	5.77±0.51	0.616±0.014	1.000±0.001	6.03±0.07	0.611±0.006	0.999±0.001	6.83±0.14	0.610±0.003	1.000±0.001
	3	4.90±1.27	0.617±0.022	1.000±0.001	4.81±0.63	0.633±0.003	1.000±0.001	5.32±0.76	0.631±0.020	1.000±0.001	5.43±0.59	0.637±0.007	1.000±0.001
	4	4.94±0.85	0.613±0.016	0.999±0.001	5.31±0.83	0.614±0.022	1.000±0.001	4.82±0.75	0.624±0.022	1.000±0.001	5.67±0.34	0.630±0.005	1.000±0.001
	6	5.53±0.43	0.604±0.019	1.000±0.001	5.17±0.59	0.618±0.020	0.999±0.001	5.83±0.62	0.608±0.003	0.999±0.001	6.22±0.93	0.618±0.019	1.000±0.001
	8	5.63±0.43	0.605±0.030	1.000±0.001	5.60±0.45	0.603±0.013	1.000±0.001	5.38±0.30	0.615±0.005	1.000±0.001	5.05±0.69	0.627±0.017	0.999±0.001

Means with standard deviations (n=3) were shown.

The rheograms of the dressing samples were fitted by the power law model, asindicated by high R^2 values ranged from 0.996 to 1.000. All dressing samples exhibited a shear-thinning (pseudoplastic) flow behavior over the observed shear rate range of 0 to 300 s^{-1}, as suggested by the *n* values within the range of *ca.* 0.4 to 0.6 (Zhen and Joyce, 2013). This result was in accordant with the previous reports (Batista *et al*., 2006; Worrasinchai *et al*., 2006). For the samples added with TMD at DE 9, increase TMD concentration thoroughly affected to increase *k* values ($p<0.05$), implying to the increased viscosity of the samples. This result was in agreement with the previous studies reporting that the emulsion viscosity tended to be developed with increasing added hydrocolloid concentration (Mandala *et al*., 2004; Udomrati *et al*., 2013; Zhen and Joyce, 2013). The present result suggested that TMD at DE 9 had a significant role on increasing viscosity of the dressing samples, which was more likely due to its capability to act as a thickener agent (Paredes *et al.,* 1989). The long-chain glucose unit fractions of TMD might attribute to increase a flow resistance (Ibanoglu, 2002). Increased viscosity of the dressings with increased concentration of TMD at DE 9 was coincident with the lowered changed $d_{4,3}$ (see **Figure 5a and 5b**) and lowered creaming rate (see **Figure 6a and 6b**) of the emulsions at a prolonged storage time. Increasing viscosity might affect to immobilize dispersed oil drops in a weak gel-like network (Dickinson, 2003), thereby retarding drop aggregation. For the samples added with TMD at DE 12 and 16, however, the viscosity of the samples was not affected by TMD incorporating ($p>0.05$). This might be related to a failure of the TMD at these DE levels on a development of drop dispersibiltiy of the dressing samples, as suggested by long term drop dispersibility (see **Figure 5c** to **5f**) and creaming index (see **Figure 6c** to **6f**). To act as a stabilizer effectively, chemical structure of maltodextrin had a crucial role. Using maltodextrins with different DEs could affect physicochemical property and stability of emulsion (Dokic-Baucal *et al*., 2004; Klinkesorn *et al*., 2004). With larger molecular size of maltodextrin with lower DE level, the TMD with DE 9 might able to form gel like network to embed dispersed oil drops and led to the improved dispesibility of the system. It should be noted that the molecular weights of TMD with DE of 9, 12, and 16 were estimated as *ca.* 13.2, 10.5, and 5.2 kg/mol, respectively

(Udomrati *et al.,* 2013). Greater increasing in viscosity of the SBO emulsions was observed, when TMD with both decreasing DE and increasing concentration was introduced (Udomrati *et al*., 2013). Viscosity of emulsions containing galactomannan in the aqueous phase was also increased with the increase of molecular weight of the polysaccharides (Wu *et al.,* 2009). The higher viscosity and greater stability as indicated by a smaller oil droplet size was observed for the sunflower oil emulsions, when corn maltodextrin with lower DE was introduced than did the higher ones (Dokic-Baucal *et al*., 2004). It has been suggested that maltodextrins with lower DE showed higher tendency to form gels, since a higher percentage of long oligosaccharide chains (Kasapis *et al.,* 1993). Reduction in gelling capability of maltodextrins with higher DE levels was supposed since a weaker system of higher percentage of low molecular weight fractions (Chronakis and Kasapis, 1995), resulting in inability to support stability of the emulsion system (Dokic-Baucal *et al*., 2004).

Considering on the effect of storage time, all of the dressings generally showed a decreasing in viscosity with storage time increasing. This behavior might be postulated due to increasing of oil droplet size with prolonging storage time. As a result of size increase, the emulsified drops were less structured, so less interaction between dispersed drops could be expected, thereby decreasing viscosity of the system (Zhen and Joyce, 2013).

5.2.2 Chemical stability

To evaluate chemical characteristics, the dressing samples were stored in an accelerated condition of 50 °C. Degree of lipid oxidation was monitored through a period of 8 weeks. **Figure 9**, **Figure 10**, and **Figure 11** illustrate the contents of peroxide value (PV), thiobarbituric reactive substances (TBARS), and *p*-anisidine (*p*-AV) present in the dressings at various storage times, respectively.

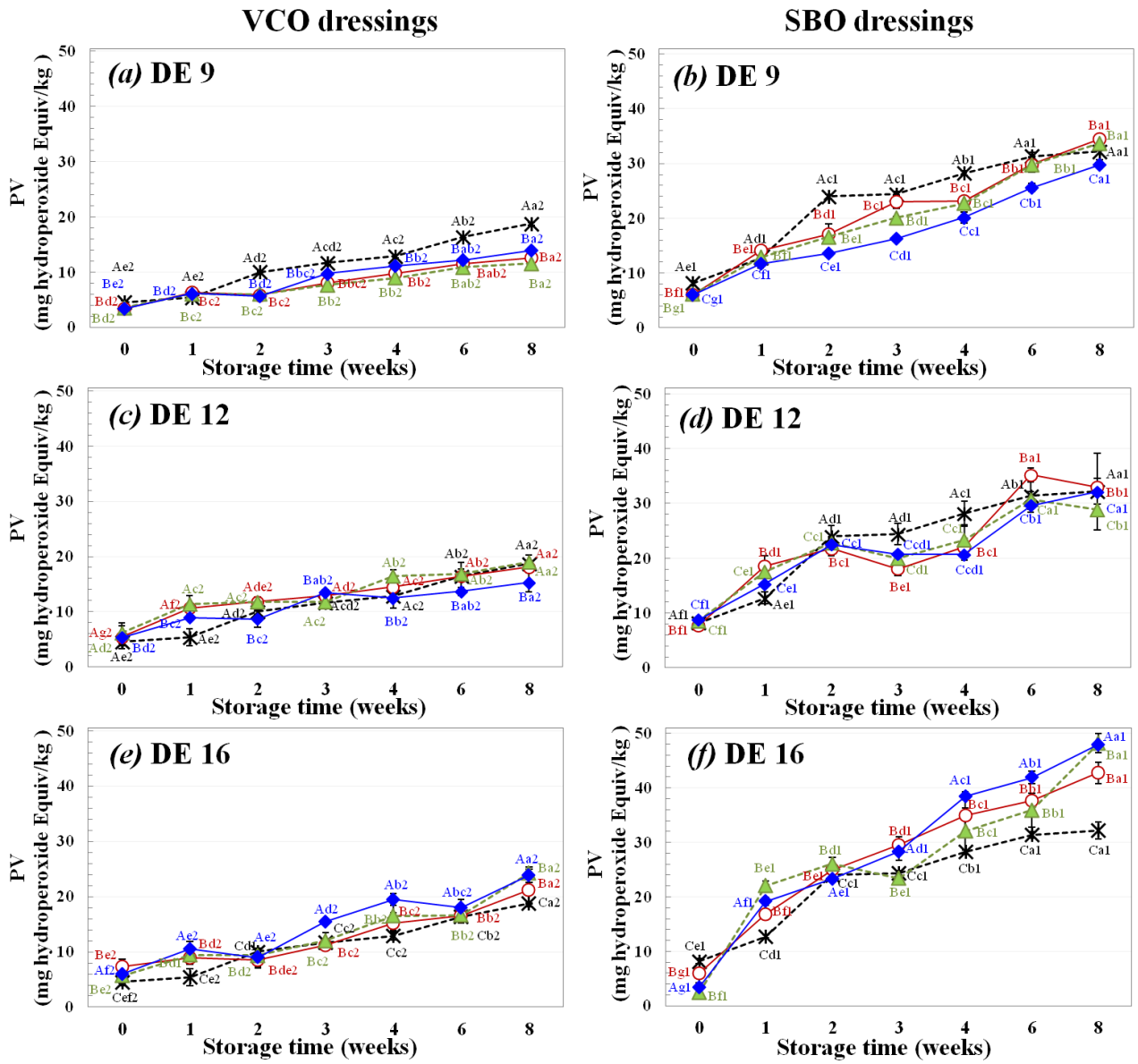

Figure 9 Storage time dependence on PV of the VCO and SBO dressings containing TMD with ***(a, b)*** DE 9, ***(c, d)*** DE12, and ***(e, f)*** DE 16 and various concentrations: 0 % (---✶---), 0.5 % (—○—), 1.5 % (---▲---), and 3 % (—◆—)

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time (p<0.05), and different lower letters indicate significant difference between means in a same TMD concentration (p<0.05).

In each DE level, different numeric letters indicate significant difference between means at a same storage time and TMD concentration (p<0.05).

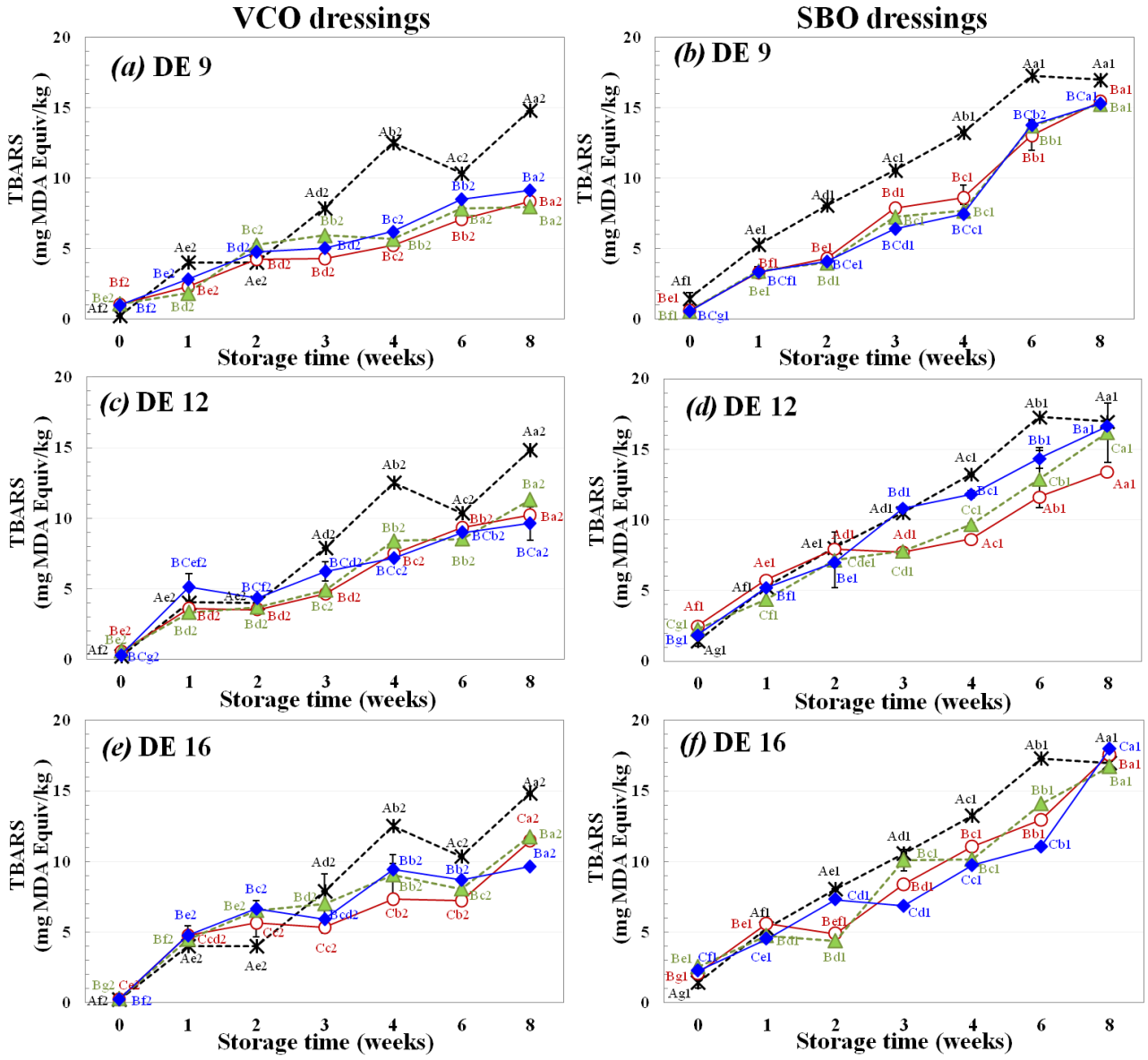

Figure10 Storage time dependence on the content of TBARS of the VCO and SBO dressings containing TMD with ***(a, b)*** DE 9, ***(c, d)*** DE12, and ***(e, f)*** DE 16 and various concentrations: 0 % (---✳---), 0.5 % (—○—), 1.5 % (---▲---), and 3 % (—◆—)

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time (p<0.05), and different lower letters indicate significant difference between means in a same TMD concentration (p<0.05).

In each DE level, different numeric letters indicate significant difference between means at a same storage time and TMD concentration (p<0.05).

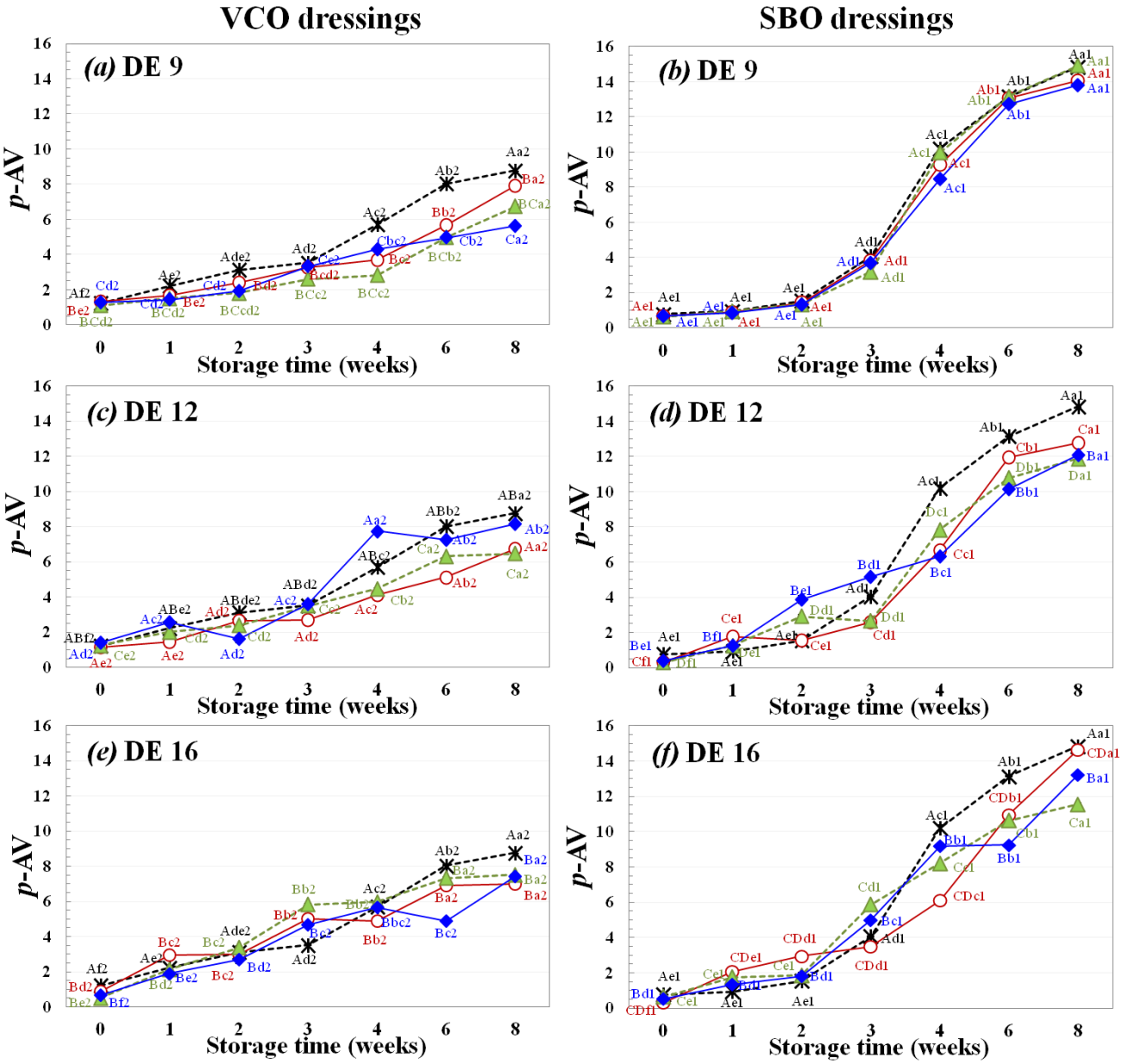

Figure 11 Storage time dependence on *p*-AV of the VCO and SBO dressings containing TMD with ***(a, b)*** DE 9, ***(c, d)*** DE12, and ***(e, f)*** DE 16 and various concentrations: 0 % (---✳---), 0.5 % (—○—), 1.5 % (---▲---), and 3 % (—◆—)

Means with standard deviations (*n*=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time ($p<0.05$), and different lower letters indicate significant difference between means in a same TMD concentration ($p<0.05$).

In each DE level, different numeric letters indicate significant difference between means at a same storage time and TMD concentration ($p<0.05$).

Lipid oxidation is one of the major chemical reactions affecting to deteriorate food quality. The oxidative process can be accelerated by light, heat, enzymes, metals, metalloproteins, and microorganisms, leading to a development of off-flavor compounds (Shahidi and Zhong, 2005). Accumulation of oxidation products, involving PV, TBAR, and *p*-AV, generally developed with prolonging storage time. Higher oxidative degree could be obviously seen for the SBO dressings compared to the VCO counterparts. Emulsified system is prone to lipid oxidation, because of a presence of higher ratio of surface area/oil volume, resulting in a greater exposure area of oil phase to water soluble pro-oxidants (McClements and Decker, 2000). Incorporating TMD could delay oxidative degree of the dressings, especially when VCO was used as a dispersed phase, especially for the TMD at DE 9. Corn maltodextrins with DE of 7.5–9 could prohibit lipid oxidation in olive oil emulsions, which was supposed since their ability to increase viscosity of the system (Di Mattia *et al*., 2014). Regarding the emulsified matrix, the initial steps of lipid oxidation, involving propagation and hydroperoxide decomposition, was kinetically delayed by the increase in viscosity, attributed to a slowed down diffusion rate of radicals with a more prolonged lifetime of undecomposed hydroperoxides (Di Mattia *et al*., 2014).

Next, total phenolic content (TPC) present in the dressings was measured at different storage times, and the result was shown in **Figure 12**. For freshly prepared samples (storage time of 0 week), higher TPC was found for the VCO dressings compared to the SBO counterparts. This might be attributed to a minimal heating process involved in a production of VCO compared to SBO (Henna and Tan, 2009). The TPC of the vegetable oils was affected by heat exposing and refining processes. Generally, unrefined oils possessed a greater TPC than refined oils, because some contents of natural polyphenols could be degraded through a refining process (Garcia *et al*., 2006). It should be noted that lowered TPC of the SBO dressings was coincidental with their lowered oxidative stability compared to the dressings made from VCO.

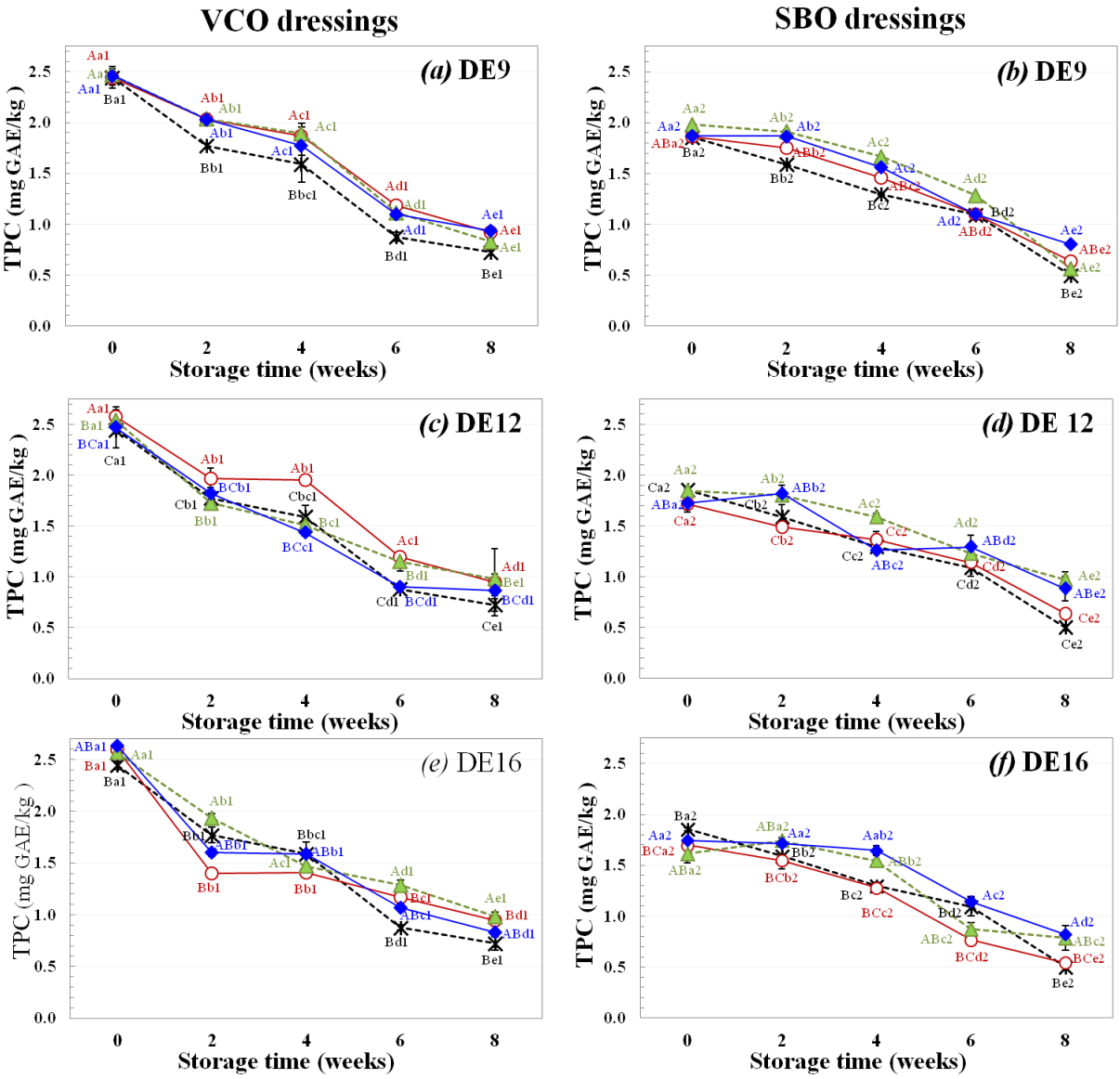

Figure 12 Storage time dependence on TPC of the VCO and SBO dressings containing TMD with ***(a, b)*** DE 9, ***(c, d)*** DE12, and ***(e, f)*** DE 16 and various concentrations: 0 % (---✳---), 0.5 % (—○—), 1.5 % (---▲---), and 3 % (—◆—)

Means with standard deviations (n=3) were shown.

In each subfigure, different upper letters indicate significant difference between means in a same storage time (p<0.05), and different lower letters indicate significant difference between means in a same TMD concentration (p<0.05).

In each DE level, different numeric letters indicate significant difference between means at a same storage time and TMD concentration (p<0.05).

Upon prolonging a storage time, TPC tended to decrease, suggesting to a degradation of phenolic compounds during storage, which might be related to oxidative stability of the samples (Henna and Tan, 2009). Phenolics could be potently employed as a natural antioxidant in various food products, attributed to their antioxidative capacities through various mechanisms, *e.g.,* chain-breaking by donating hydrogen atom to peroxyl, alkoxyl and lipid alkyl radicals and converting them to non radical products (Reische, 2008). From the present results, one can see that adding with TMD DE 9 could maintain TPC of the dressings with greater amount than did the control sample. This tendency was coincidental with the lowered PV (*p*-aV) of the former emulsions as shown in the previous results (see **Figure 9** to **Figure 11**).

Overview from the results, one can see that TMD DE 9 could successfully improve colloidal and oxidative stability of the dressings. Incorporating TMD DE 9 at 3 % led to the greatest emulsion dispersibility, as indicated by the lowest creaming rate. Consequently, sensorial acceptability of the VCO and SBO dressing recipes added with TMD DE 9 at 3 % was further studied.

5.2.3 Sensory evaluation

Sensorial acceptability of the VCO dressings stabilized by TMD DE 9 at 3 % was evaluated by 40 panelists, by comparing with the counterparts made from SBO. **Table 9** shows the sensorial scores of the dressing samples.

SBO dressings possessed higher scores on appearance and color than the VCO dressing ($p<0.05$). By incorporating TMD, score on taste of the VCO dressings was higher than the recipe without TMD ($p<0.05$). There was no significant difference on odor score for all dressings ($p>0.05$), which might be due to a presence of various components such as mustard and vinegar that masked the odor of VCO. Higher acceptance on viscosity was found for the dressings added with TMD, irrespectively of oil type ($p<0.05$). This result suggested that TMD could modify viscosity of the dressings to preferable range of the panelists. For the VCO dressings, TMD incorporation affected to increase acceptability in taste of the product ($p<0.05$). Considering on the overall likeness, the highest score was

found for the dressings incorporated with 3 % TMD, regardless of oil types. Thus, VCO could be employed to prepare salad dressing with appreciable sensory characteristic, especially in a presence of TMD.

Table 9 Scores of sensory evaluation for salad dressings made from VCO and SBO without and with 3 % TMD

Attributes	VCO dressings		SBO dressings	
	0 % TMD	3 % TMD	0 % TMD	3 % TMD
Appearance	6.45±1.18^{b}	6.48±1.06^{b}	7.55±0.90^{a}	7.03±1.05^{a}
Color	6.38±1.25^{b}	6.33±1.25^{b}	7.20±1.09^{a}	7.13±0.85^{a}
Odor	6.08±1.40^{a}	6.10±1.41^{a}	6.58±1.24^{a}	6.33±1.42^{a}
Viscosity	6.34±0.74^{c}	7.08±0.97^{ab}	6.83±1.22^{b}	7.20±0.65^{a}
Taste	6.20±1.18^{b}	6.83±1.22^{a}	6.90±1.26^{a}	7.00±1.26^{a}
Overall likeness	6.33±1.23^{c}	6.93±0.80^{ab}	6.68±1.16^{bc}	7.18±1.01^{a}

Mean values with standard deviation (n=40) were shown.

Different letters indicate significant difference between means in a same row (p<0.05).

From all points of view, a comparable colloidal stability between VCO and SBO dressings was observed. Nonetheless, higher oxidative stability of VCO samples than did SBO counterparts was markedly evident. The higher content of phenolic compounds was found for the VCO dressing. Improvement on dispersibility of the dressings could be accomplished by incorporating TMD at DE 9, especially at increased concentration. TMD could also maintain pH and color changes of the dressings during a storage of 8 weeks. Comparable sensorial acceptability between the VCO and SBO dressings was observed in a presence of 3 % TMD (DE 9). The present study suggested that VCO could be employed to prepare salad dressing with desirable physicochemical stability and enriched phenolic compounds.

5.3 Improvement on frying stability SBO via blending technique with coconut oil (CO)

Next, improvement on frying stability of SBO was studied through blending technique using CO. SBO was blended with CO at various mixing ratios, *i.e.,* the volume ratios of SBO:CO were 100:0 (control), 80:20, 60:40, and 50:50. The blended oils were employed to fry different foods, including protein based–, *i.e*., chicken nuggets, and carbohydrate based foods, *i.e*., French fries, for several repeated cycles (0–5 cycles). Then, properties of the processed foods and the used oils were investigated.

5.3.1 Characteristics of the frying oils

The characteristics of the oils used for several frying cycles were investigated by measuring physical and chemical properties. **Table 10** and **Table 11** show color change of the blended oil used to cook chicken nuggets and French fries for several frying cycles, respectively

By increasing numbers of frying cycles, color of the oils was affected as evidence by decreasing in lightness and redness scores, as well as increasing in yellowness. From **Table 10**, the lightness (L^*) of the oils was decreased with the increase numbers of frying cycles, ($p<0.05$). Increasing the CO content to the blended oils could rise L^* of the oils and the blending ratio of 50:50 provided the highest lightness score ($p<0.05$). Increase numbers of frying cycles significantly affected to all color parameters of the oils, irrespectively of blending ratio ($p<0.05$). By blending with CO, redness (a^*) and yellowness (b^*) scores of the blended oils were lower than those observed for the SBO ($p<0.05$). Deterioration of several vegetable oils, including palm olein, canola, and soybean oils with increased numbers of frying cycle was suggested by the raised a^* and b^* scores (Abdulkarim *et al.,* 2007).

Table 10 Color of the blended oils used to cook chicken nuggets for several repeated frying cycles

SBO:CO	number of frying cycle	color parameters		
		*L**	*a**	*b**
100:0	0	82.19 ± 0.02 Ca	-3.50 ± 0.02 Af	11.27 ± 0.04 Af
	1	75.43 ± 0.01 Cb	-3.03 ± 0.01 Ae	42.55 ± 0.03 Ae
	2	64.48 ± 0.03 Cc	7.89 ±0.04 Ad	65.45 ±0.16 Ad
	3	56.90 ± 0.12 Cd	15.67 ± 0.14 Ac	71.50 ± 0.23 Ac
	4	42.39 ± 0.89 Ce	28.28 ± 0.23 Ab	75.55 ± 2.71 Ab
	5	40.26 ± 0.02 Cf	28.76 ± 0.02 Aa	73.09 ± 0.50 Aa
80:20	0	82.52 ± 0.01 Ba	-3.64 ± 0.02 Bf	12.16 ± 0.03 Bf
	1	77.36 ± 0.03 Bb	-4.16 ± 0.03 Be	37.57 ± 0.06 Be
	2	72.15 ± 0.01 Bc	-0.56 ± 0.04 Bd	50.61 ± 0.11 Bc
	3	64.76 ± 0.02 Bd	8.38 ± 0.05 Bc	66.78 ± 0.11 Bc
	4	55.09 ± 0.04 Be	19.28 ± 0.08 Bb	72.98 ± 0.09 Bb
	5	45.13 ± 0.02 Bf	27.52 ± 0.04 Ba	71.26 ± 0.42 Ba
60:40	0	82.75 ± 0.01 Ba	-3.62 ± 0.01 Bf	12.48 ± 0.04 Bf
	1	76.37 ± 0.08 Bb	-3.71 ± 0.02 Be	30.72 ± 0.02 Be
	2	69.64 ± 0.01 Bc	3.22 ± 0.02 Bd	57.59 ± 0.08 Bd
	3	63.43 ± 0.01 Bd	9.85 ± 0.03 Bc	66.61 ± 0.08 Bc
	4	54.86 ± 0.01 Be	19.45 ± 0.10 Bb	72.44 ± 0.25 Bb
	5	47.77 ± 0.01 Bf	25.09 ± 0.03 Ba	70.32 ± 0.23 Ba
50:50	0	82.54 ± 0.27 Aa	-3.51 ± 0.13 Cf	11.72 ± 0.78 Bf
	1	76.42 ± 0.02 Ab	-3.38 ± 0.03 Ce	34.83 ± 0.04 Be
	2	68.77 ± 0.01 Ac	3.07 ± 0.03 Cd	55.74 ± 0.06 Bd
	3	61.25 ± 0.09 Ad	11.79 ± 0.18 Cc	69.18 ± 0.26 Bc
	4	57.99 ± 0.03 Ae	14.66 ± 0.05 Cb	70.93 ± 0.12 Bb
	5	47.45 ± 0.06 Af	25.15 ± 0.07 Ca	73.98 ± 0.14 Ba

Means ± Std (n=5) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) (p<0.05).

Table 11 Color of the blended oils used to cook French fries for several repeated frying cycles

SBO:CO	numbers of frying cycle	color parameters		
		*L**	*a**	*b**
100:0	0	81.55±0.01Ca	-3.13±0.03Ca	9.85±0.04Af
	1	80.10±0.01Cb	-5.15±0.01Cb	16.28±0.02Ae
	2	79.11±0.04Cc	-6.42±0.02Cc	23.00±0.02Ad
	3	78.51±0.01Cd	-7.15±0.02Cd	32.74±0.03Ac
	4	77.96±0.01Ce	-7.12±0.03Cd	36.94±0.06Ab
	5	77.26±0.01Cf	-7.13±0.01Cd	40.62±0.02Aa
80:20	0	81.05±0.01ABa	-2.70±0.02BCa	8.35±0.03Bf
	1	81.43±0.01ABab	-5.13±0.02BCb	16.43±.01Be
	2	80.70±0.01ABc	-6.71±0.03BCcd	22.95±0.04Bd
	3	79.36±0.01ABd	-6.30±0.02BCc	21.58±0.02Bc
	4	79.22±0.01ABd	-6.26±0.02BCc	30.74±0.02Ba
	5	78.10±0.01ABe	-6.80±0.02BCd	29.66±0.06Bab
60:40	0	80.55±0.01ABa	-2.35±0.02Aa	7.08±0.02BCde
	1	80.00±0.01ABab	-2.51±0.02Aab	7.60±0.03BCde
	2	79.53±0.02ABab	-2.77±0.01Ab	8.25±0.03BCd
	3	79.62±0.01ABab	-4.26±0.02Ac	13.82±0.04BCc
	4	79.49±0.01ABb	-5.42±0.02Ad	19.47±0.02BCb
	5	78.95±0.01ABc	-5.50±0.02Ad	22.82±0.04BCa
50:50	0	80.57±0.01Aa	-2.98±0.01ABa	5.56±0.02Be
	1	80.69±0.01Aa	-3.12±0.01ABab	9.72±0.03Bd
	2	80.65±0.01Aa	-5.25±0.02ABc	17.97±0.01Bc
	3	80.71±0.01Aa	-6.53±0.01ABde	26.41±0.02Bb
	4	79.54±0.01Ab	-6.40±0.03ABd	25.94±0.03Bb
	5	79.38±0.03Ac	-6.66±0.02ABde	35.45±.02Ba

Means ± Std (n=5) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) (p<0.05).

Considering on French-fries cooking, the largest change in *L** was found for the control oil (100:0), suggesting to the least thermal stability of this oil: For the control oil, *L** thoroughly increased with frying cycle ($p<0.05$), whereas *L** was significantly changed after frying for 2, 4, and 4 cycles for the oils blended at ratios of 80:20, 60:40, and 50:50 ($p<0.05$), respectively. The smallest color change was found for the 60:40 blended oil as suggested by *b** index: The *b** values were markedly increased after frying for 1 cycle for the oil blending ratios of 100:0, 80:20 and 50:50 ($p<0.05$), whereas the 60:40 blended oil could retain *b** through the 2nd cycle of frying ($p>0.05$).

The present results implied that improvement on color stability of SBO against frying process could be accomplished by blending with CO. Increasing frying cycle led to more pronounced color change of the oils. Darkening of the oils during frying process could be found since a formation of some compounds involving polymerized unsaturated carbonyl and non–polar compounds, *e.g.*, hydroperoxides, conjugated dienoic acids, ketones, and hydroxides (Gutierrez *et al*., 1988; Yaghmur *et al*., 2001).

Next, the chemical characteristics of the oils as affected by frying process were investigated. **Figure 13** depicts fatty acid compositions of native SBO and CO. The fatty acids predominantly present in SBO (CO) were unsaturated fatty acids, *i.e.,* C18:2 and C18:3 (saturated fatty acids, *i.e*., C12:0 and C14:0). The short and medium chain fatty acids (C8:0 – C14:0) were found only in CO, whereas C18:3 was observed just for SBO. To observe change in chemical composition of the blended oil along frying process, fatty acid compositions of the blended oils used to cook nuggets and French-fries were measured at various number of frying cycle, and the results were shown in **Figure 14** and **Figure 15**, respectively.

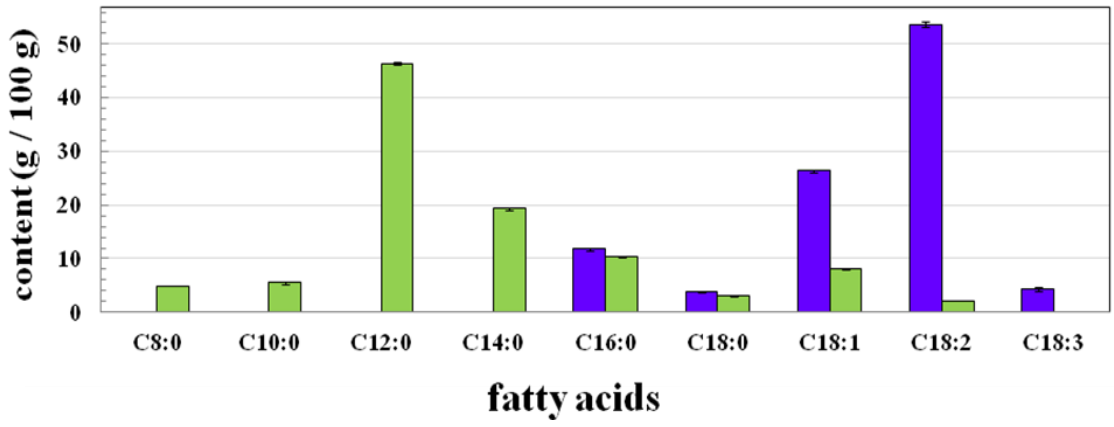

Figure 13 Fatty acid compositions of SBO (■) and CO (■)

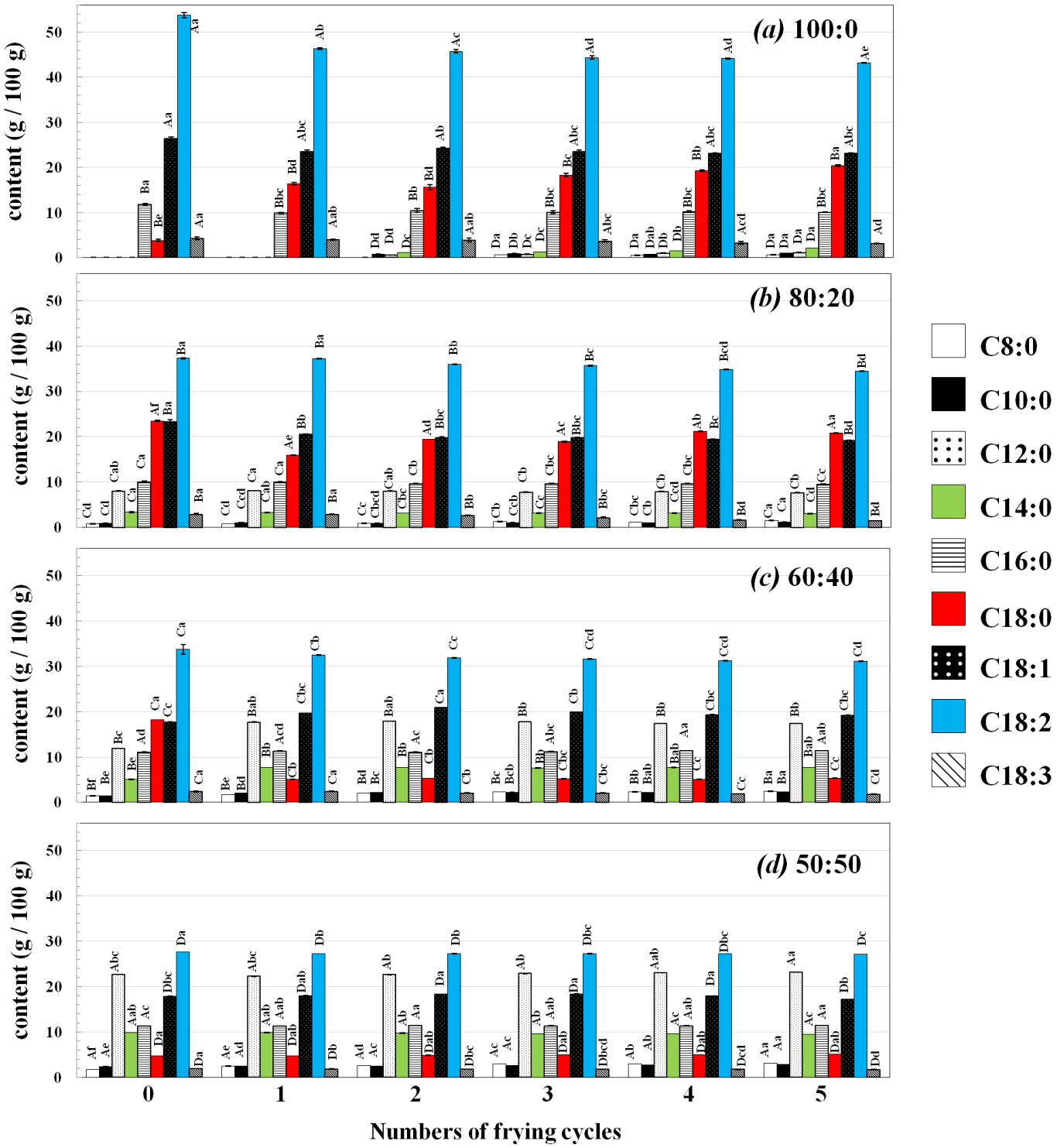

Figure 14 Fatty acid compositions of the blended oils used to cook chicken nuggets at various repeated frying cycles. The blending ratio of SBO:CO were ***(a)*** 100:0, ***(b)*** 80:20, ***(c)*** 60:40, and ***(d)*** 50:50.

Means with Std (n=3) were shown. The different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) (p<0.05).

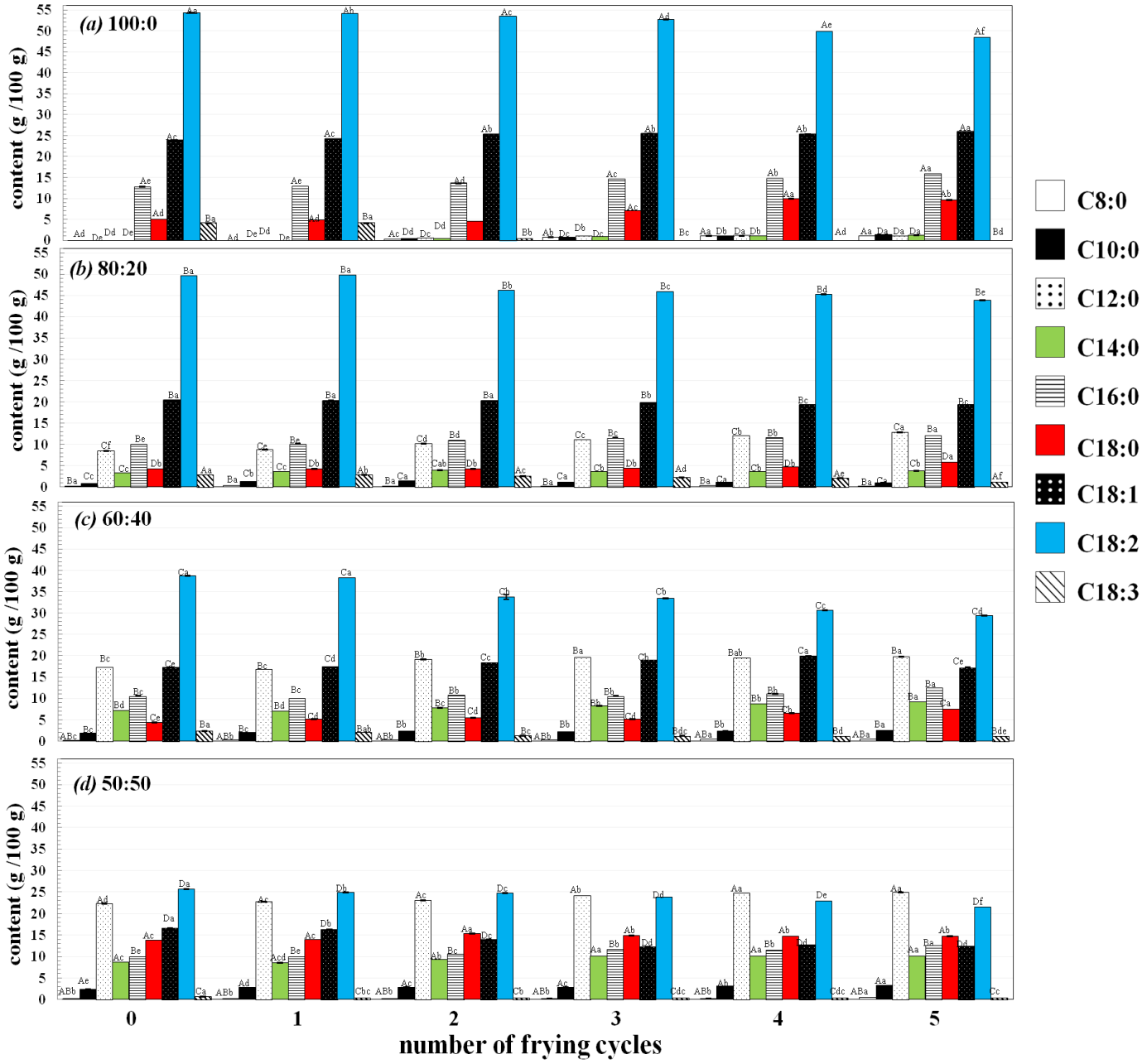

Figure 15 Fatty acid compositions of the blended oils used to cook French-fries at various repeated frying cycles. The blending ratio of SBO:CO were ***(a)*** 100:0, ***(b)*** 80:20, ***(c)*** 60:40, and ***(d)*** 50:50.

Means with Std (n=3) were shown. The different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) (p<0.05).

After blending together, the fatty acid profiles of the oil samples were changed depending on the content of added CO. By increasing the content of CO, the amounts of C8:0, C10:0, C12:0, and C14:0 were significantly thoroughly increased (p<0.05), whereas the amounts of C18:0, C18:1, C18:2, and C18:3 were decreased (p<0.05). The oils blended at the ratio of 50:50 and 60:40 exhibited the highest C16:0 content (P<0.05). The C18:1 and C18:2 were predominantly observed in all oil samples. This could be attributed to the major fatty acid compositions present in the CO that affected to modify the fatty acid profiles of the oils after blending.

Upon increasing the numbers of repeated frying cycles, fatty acid profiles of the oils were affected. Regarding to the frying using nuggets as a material (see **Figure 14**), the contents of unsaturated fatty acids, *i.e*., C18:1, C18:2, and C18:3, tended to decrease by increasing the frying cycle. Nonetheless, the amounts of short chain fatty acids, *i.e.,* C8:0–C14:0, were increased.

For frying using French-fries as a model (**see Figure 15**), the contents of C18:2 was thoroughly decreased with increasing numbers of frying cycle for the 100:0 and 50:50 blended oils (p<0.05), whereas the C18:2 contents could be preserved through the 2nd frying cycle in the case of 80:20 and 60:40 blended oils (p>0.05). The oil blended at 80:20 ratios showed a markedly decreased C18:3 content since the 1st cycle (p<0.05), but the C18:3 content was not changed till the 2nd frying cycle for the 60:40 blended oil (p>0.05). The present results implied that by blending with CO thermal stability of SBO could be successfully improved, especially at the mixing ratio of 60:40.

Reduction in unsaturated fatty acid content observed in the present work was in agreement with the other studies, suggesting a susceptibility to degradation during frying of unsaturated fatty acids (Bracco *et al*., 1981; Melton *et al*., 1994; Tynek *et al*., 2001; Abdulkarim *et al*., 2007; Casal *et al*., 2010; Alireza *et al*., 2010; Marmesat *et al*., 2012; Wang *et al*., 2013). A great reduction in C18:3 of canola oil during frying process was reported (Alireza *et al*., 2010). Tynek *et al*., (2001) reported a relative loss of C18:2 fatty acid of oil after frying. Wang *et al*., (2013) also observed a significantly diminishing in C18:2 and C18:3 of

SBO after frying. Considering on the change of saturated fatty acids, increment of C16:0 and C18:0 for RBD palm and canola oils during along frying process was reported and expected since a breaking of double and triple bonds in unsaturated fatty acids, which were transformed into the counterparts with the same or shorter of carbon chain (Alireza *et al*., 2010).

Figure 16 shows iodine value (IV) of the blended oils used to cook chicken nuggets for several repeated frying cycles. Increase number of repeated frying led to lower IV of the oils, suggesting to deterioration in oil quality. Destruction of C=C by oxidation and polymerization upon frying indicating by lowered IV was observed in various oils, *e.g.,* canola (Normand *et al.,* 2006; Alireza *et al*., 2010; Farhoosh *et al*., 2009), sunflower (Normand *et al.,* 2001; Pangloli *et al*., 2002; Juárez *et al*., 2011; Marmesat *et al.,* 2012), soybean (Juárez *et al.,* 2011), and corn oils (Naz *et al.,* 2005; Sunisa *et al*., 2011; Ramadan and Wahdan, 2012). After blending with CO, the IV of the oil samples thoroughly decreased with increasing CO content ($p<0.05$), which was in agreement with the fatty acid composition measurement. CO blending could retard a reduction of polyunsaturated fatty acids (PUFAs) content when frying cycle was increased: The IV significant decreased since the first frying cycle for soybean oil ($p<0.05$), whereas the IV was maintain as the initial value till the first (third) cycle when CO was blended at 80 (60) %, respectively ($p>0.05$). Regarding on the present result, the most suitable blending ratio was suggested at 60:40.

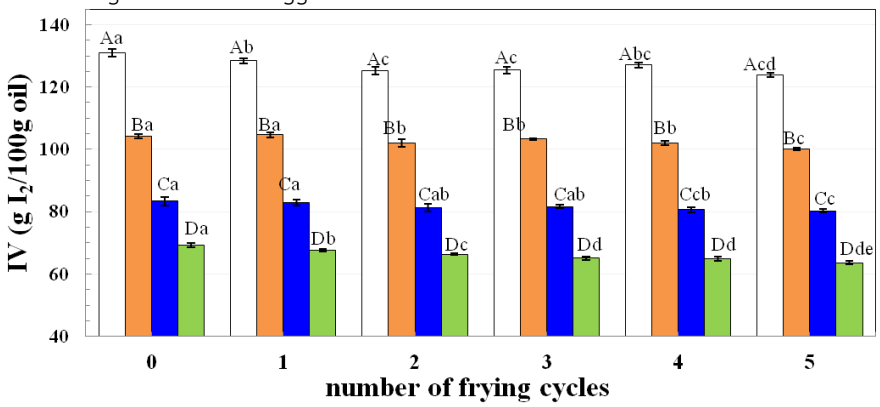

Figure 16 IV of the blended oils used to cook chicken nuggets for several repeated cycles. The blending ratios of SBO:CO were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■). Means with standard deviations were shown ($n=3$). The different capital letters (small letters) indicate significant difference between means at the same number of frying cycle (oil blending ratio) ($p<0.05$).

Change in IV of the blended oils used to process French-fries at different repeated frying cycles was illustrated in **Figure 17**. By mixing with CO, IV of SBO was decreased, especially at the increased CO mixing volume ($p<0.05$). Blending with CO at the appropriate ratio, *i.e.*, 60:40 in the present result, could retard IV diminishing, suggesting to the improved frying stability of the oil: The IV of the oil blended at ratios of 100:0, 80:20, and 50:50 was markedly decreased since the 1st frying cycle ($p<0.05$), whereas the IV of 60:40 blended oil could be retained through the 2nd frying cycle ($p>0.05$).

Improved frying stability of SBO by blending with CO could be attributed to increasing of saturation degree of the oil. It has been suggested that oils with high unsaturation degree was more sensitive for thermal degradation compared to the saturated counterparts (Velasco and Dobarganes, 2002; Gómez-Alonso *et al.,* 2003; Alireza *et al*., 2010; Marmesat *et al.,* 2012). Romero *et al*., (2006) suggested that oils with a low in C18:2 and high in C18:1 tended to be oxidized more readily than oils with higher in C18:2 and lower in C18:1, which have a greater tendency to undergo polymerization. Moreover, it was evident that formation of polymer in thermal exposed oil increased with degree of oil unsaturation (Marmesat *et al.,* 2012). Good frying stability of olive (Velasco and Dobarganes, 2002; Gómez-Alonso *et al.,* 2003) and palm olein (Alireza *et al*., 2010) oils was pronounced due to their less content in PUFAs.

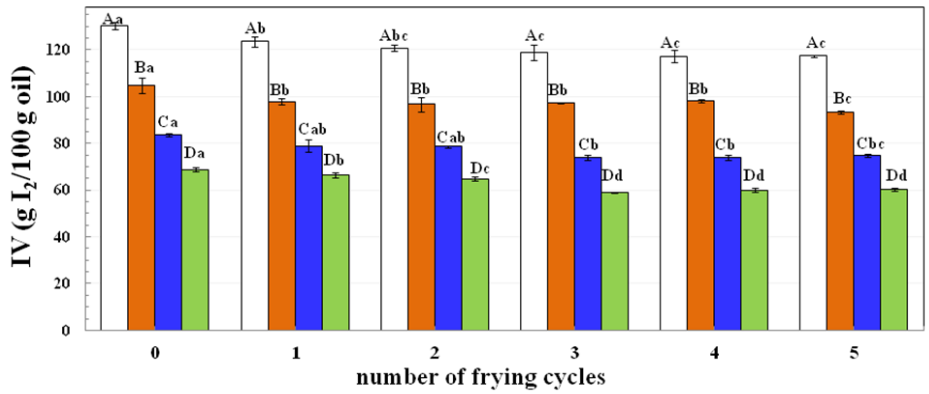

Figure 17 IV of the blended oils used to cook French-fries for several repeated cycles. The blending ratios of SBO:CO were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■). Means with standard deviations were shown ($n=3$). The different capital letters (small letters) indicate significant difference between means at the same number of frying cycle (oil blending ratio) ($p<0.05$).

Frying stability of the blended oils was further investigated using a differential scanning calorimetric (DSC) method. **Figure 18** illustrates DSC thermogram of the fresh SBO. Three peaks, *i.e.,* A: high temperature, B: medium temperature, and C: low temperature, were observed which were correlated to three triacylglycerol (TAG) groups of monounsaturated TAG, diunsaturated TAG, and triunsaturated TAG, respectively (Tan *et al*., 2001).

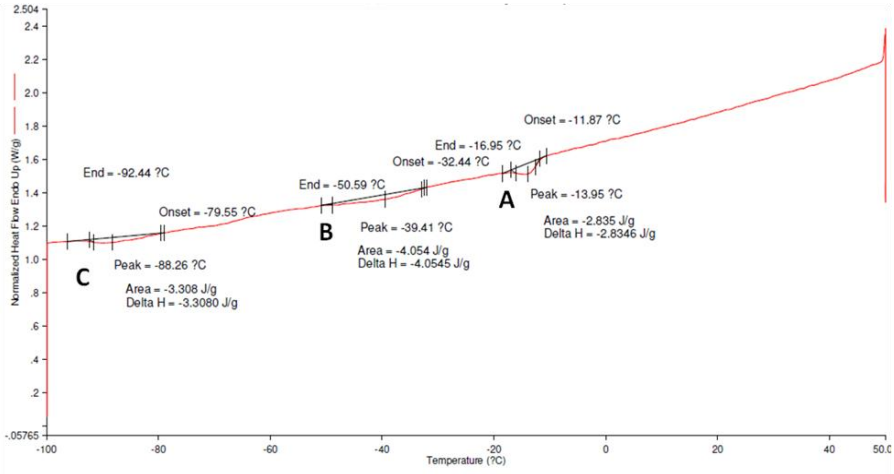

Figure 18 DSC thermogram of native SBO

Curve area of these three exothermal peaks could be used to determine thermal stability of the oils. **Table 12** shows areas of the exothemal peaks of the blended oils used to cook chicken nuggets for several repeated cycles.

From the DSC thermograms, the oil samples with the mixing ratio of 100:0 and 50:50 showed the least stability against thermal degradation, as suggested by no noticeable of triunsaturated TAG after the 5th frying cycle. The highest maintained amounts of diunsaturated TAG and triunsaturated TAG were found for the oil blended at ratio of 60:40, implying to the highest stability against thermal degradation of the oil. This behavior was coincidental with other parameters previously reported.

Table 12 Percentage areas of exothermal peaks of the blended oils after using to cook chicken nuggets for 0, 1, 3, and 5 repeated cycles.

SBO:CO	Frying cycle	Peak area (%)		
		monounsaturated TAG	diunsaturated TAG	triunsaturated TAG
100:0	0	32.44	39.76	27.80
	3	31.61	29.74	38.64
	5	100	nd	nd
80:20	0	58.18	17.87	23.95
	3	60.65	23.67	15.68
	5	48.64	27.35	24.01
60:40	0	21.32	47.58	31.10
	3	17.93	52.63	29.44
	5	13.87	60.23	25.90
50:50	0	18.01	66.03	33.97
	3	13.84	61.75	24.42
	5	33.51	66.49	nd

Table 13 shows areas of the exothemal peaks from DSC thermograms of the blended oils used to cook French-fries for different repeated frying cycles. The 100:0 and 50:50 blended oils possessed the least stability against thermal degradation, as suggested by no noticeable of triunsaturated TAG after the 5th frying cycle. The highest maintained amounts of PUFAs were found for the 60:40 blended oil, implying to the highest thermal stability of the oil at this blending ratio.

Table 13 Percentage areas of exothermal peaks of the blended oils after using to cook French-fries for 0, 3, and 5 repeated cycles.

SBO:CO	Frying cycle	Peak area (%)		
		monounsaturated TAG	diunsaturated TAG	triunsaturated TAG
100:0	0	34.11	33.96	31.93
	3	36.14	39.30	24.56
	5	41.84	48.05	10.10
80:20	0	35.43	38.69	25.88
	3	33.55	44.94	21.51
	5	48.71	36.94	14.35
60:40	0	42.58	35.76	21.66
	3	39.60	41.69	18.71
	5	34.62	52.91	12.47
50:50	0	43.33	38.61	18.05
	3	76.42	23.58	nd
	5	87.29	12.71	nd

The stability of the oils against frying deterioration was further determined by measuring peroxide value (PV), *p*-anisidine value (*p*-AV), free fatty acid (FFA) contents. The PV, *p*-AV, and FFA of the blended oils used to process chicken nuggets (French-fries) were shown in **Figure 19** (**Figure 20**), respectively.

From **Figure 19a**, the control oil showed the highest PV that the other blended oils ($p<0.05$). By blending with CO, PV of SBO could be reduced, and the lowest PV was observed for the 60:40 and 50:50 blended oils ($p<0.05$). For the control and 80:20 blended oils, the highest PV was observed after frying for 1 cycle ($p<0.05$), and then declined ($p<0.05$). With a progressive of lipid oxidation, decreasing of PV could be supposed since a decomposition of hydroperoxides and/or their interaction with other residues in oils

(Pownell *et al.,* 2010). For the oils blended at ratios of 60:40 and 50:50, better oxidative stability compared to the former cases was suggested by the maintained PV till the second and third frying cycle, respectively. This tendency implied to the improved stability of SBO by blending with CO, which was in agreement with the previous results.

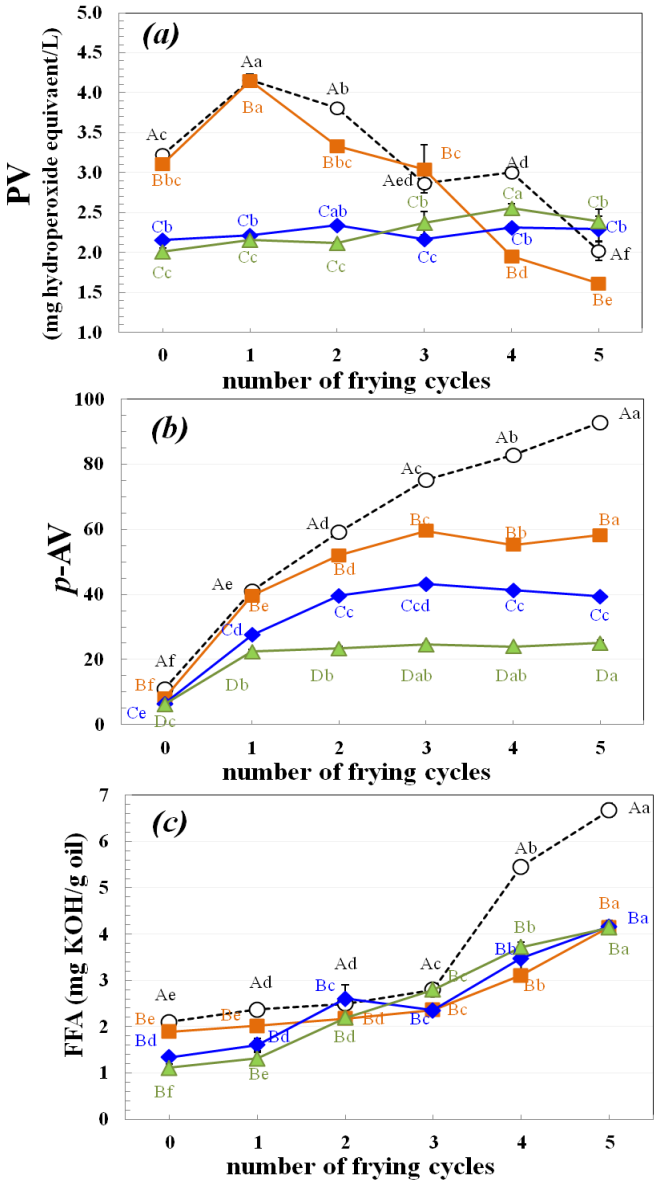

Figure 19 (*a*) PV, **(*b*)** *p*-AV, and **(*c*)** FFA of the blended oils used to cook chicken nuggets for several repeated cycles. The blending ratios of SBO:CO were 100:0 (○), 80:20 (■), 60:40 (◆), and 50:50 (▲).

Means with Std (*n*=3) were shown. The different capital letters indicate significant difference between means at the same number of frying cycle. The different small letters indicate significant difference between means at the same oil blending ratio.

Considering on *p*-AV (see **Figure 19b**), *p*-AV increased with numbers of repeated frying cycle. The highest *p*-AV increasing was evident for the control oil ($p<0.05$), whereas blending with CO could lower *p*-AV development, especially for the 50:50 blended oil. This trend was correlated with the PV measurement indicating that oxidative stability of the SBO could be improved by blending with CO, especially at increase CO content.

To evaluate frying stability of the oils, FFA was used as the index for thermal hydrolytic degradation (see **Figure 19c**). SBO exhibited the highest FFA content through the frying ($p<0.05$). Increase number of frying cycle led to increased FFA of the oils. However, the FFA content of the oils could be lowered by mixing with CO ($p<0.05$), suggesting to improved thermal stability of the SBO by blending with CO.

Prolonged frying period also affected to increase PV (see **Figure 20a**) of the oils used to cook French-fries, irrespective of blending ratios. The largest PV development could be observed for the control oil, suggesting to its inferior stability against thermal oxidation compared to the oils at other blending ratios. PV of the 100:0 and 80:20 blended oils was significantly higher than those found for the 60:40 and 50:50 blended oils ($p<0.05$). Development of *p*-AV was thoroughly observed with increasing number of frying cycles (see **Figure 20b**). The lowest *p*-AV increasing was evident for the 60:40 blended oils ($p<0.05$), suggesting to its better stability than the others, which was in agreement with the result of PV measurement. Considering on FFA (see **Figure 20c**), FFA of the oils increased with a number of repeated frying cycles. The highest FFA could be found for the control oil ($p<0.05$), whereas the comparable FFA was observed when CO was blended to the SBO ($p>0.05$).

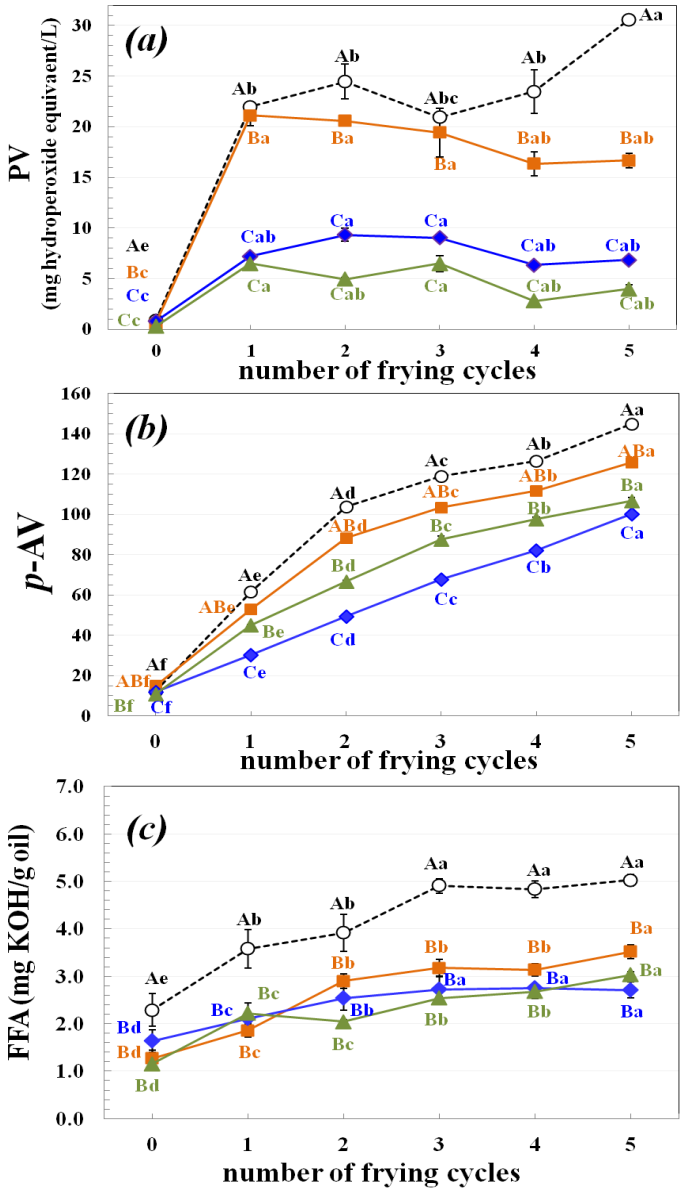

Figure 20 (*a*) PV, **(*b*)** *p*-AV, and **(*c*)** FFA of the blended oils used to cook French-fries for several repeated cycles. The blending ratios of SBO:CO were 100:0 (○), 80:20 (■), 60:40 (◆), and 50:50 (▲).

Means with Std (*n*=3) were shown. The different capital letters indicate significant difference between means at the same number of frying cycle. The different small letters indicate significant difference between means at the same oil blending ratio.

As comparing between two food commodities, one can see higher pronounced degradation for the oils used to cook French-fries than did the ones used for chicken nuggets, as suggests by higher PV and *p*-AV of the used oils. Blending ratio providing the oils with the highest tolerant against thermal degradation was also different, *i.e.,* 50:50 and 60:40 for the oils used to process chicken nuggets and French-fries, respectively.

Next, total polar matters (TPM) present in the oils after use for frying at different repeated cycles were evaluated. TPM of the blended oils employed to cook chicken nuggets was illustrated in **Figure 21**.

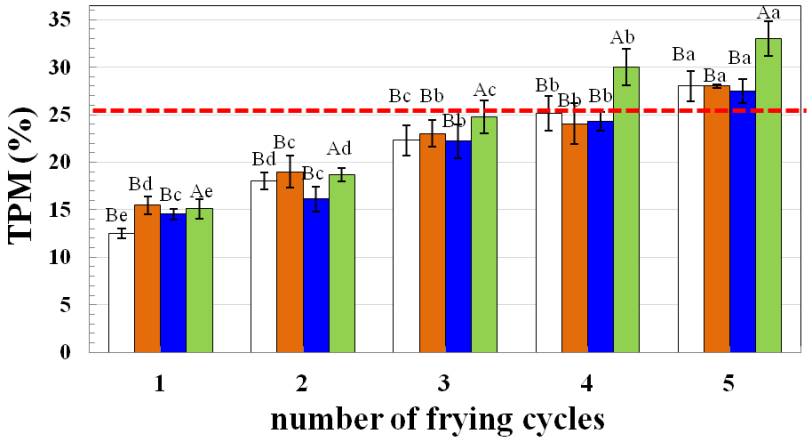

Figure 21 TPM of the blended oils used to cook chicken nuggets for several repeated cycles. The blending ratios of SBO:CO were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■).

**The dash line indicates the discard level of TPC for vegetable oils* (Firestone, 1993).

With extension of frying cycle, TPM of the control and 50:50 blended oils was thorough increased (p<0.05). The 50:50 blended oil possessed the highest TPM compared to the others (p<0.05). The most stable oils was evident for the 60:40 blended oil, as suggested by a significant change of TPM after the second frying cycle (p<0.05), whereas a markedly change of TPM was observed after the first frying cycle for the other blended oils (p<0.05).

Next, TPM of the oils used to process French-fries was illustrated in **Figure 22**. TPM of the oils was increased along frying process. As in accordance with the result in **Figure 20**, the 50:50 blended oil possessed the highest TPM compared to the other oil samples (p<0.05). After the 5th cycle, the 50:50 blended oil showed a higher TPM than the discarded level of frying oil (*i.e.*, 24–27 %, Firestone, 1993), whereas the other oil samples possessed the TPM in acceptable level. The present result suggested that the 50:50 blended oil might not suitable to be used in frying process.

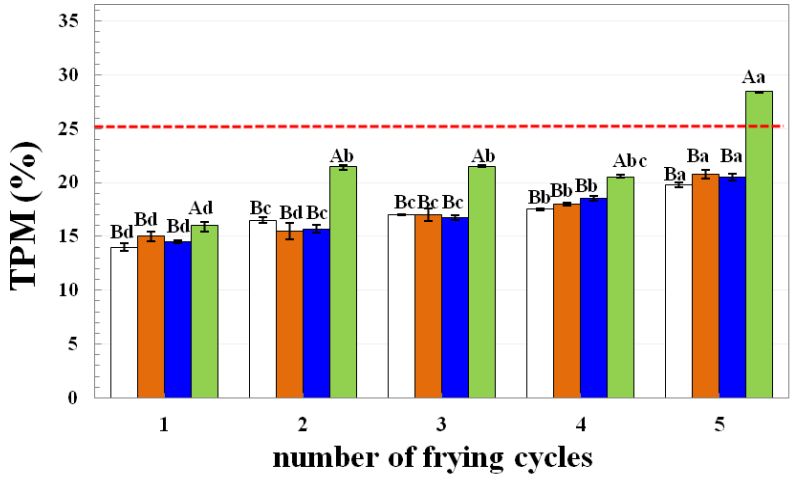

Figure 22 TPM of the blended oils used to cook French-fries for several repeated cycles. The blending ratios of SBO:CO were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■).

**The dash line indicates the discard level of TPC for vegetable oils* (Firestone, 1993).

Along frying process, accumulation of various degraded compounds with polarity, *e.g.,* alcohol, aldehydes, ketones, and partial glycerides, could be occurred, resulting in increasing of TPM (Srivastava and Semwal, 2015). Occurrence of polar compounds could be delayed by blending with more saturated oils. The frying time resulting in TPM higher than 24 % was extended from 7.3 h to 15.97, 13.7, and 8.2 h when canola oil was blended with palm olein, olive, and corn oil, respectively (Farhoosh *et al*., 2009). By blending with palm olein, oxidative resistance of canola oil along deep frying process could significantly improve (Farhoosh *et al*., 2009). Note that the frying oil containing more than 24-27 % TPC is recommended to be discarded (Firestone, 1993). Therefore, the present work indicated that the 80:20 and 60:40 blended oils could be used to process chicken nuggets for 4 cycles, whereas the 100:0, 80:20, and 60:40 could be employed to cook French-fries for 5 cycles.

From the present results, one can see that stability against thermal degradation of SBO could be successfully improved by blending with CO at the optimum ratio, *i.e.,* . This was supposed since the modified fatty acid composition by increasing saturation degree of the oils after blending. The blended oil samples with the highest stable was evident for the 50:50 and 60:40 blended oils, when chicken nuggets and French-fries were used as food materials, respectively.

5.3.2 Fried product analysis

Next, characteristics of the fried foods were investigated, using the food samples fried in fresh oils as a control. Firstly, change in chemical compositions of the food materials was observed. **Table 14** shows chemical compositions of raw nuggets.

Table 14 Chemical composition of raw chicken nuggets

chemical composition	content (%, wet basis)
crude protein	19.07 ± 0.20
crude fat	1.83 ± 0.21
moisture	75.38 ± 0.01
ash	2.04 ± 0.06

Frying affected to alter the moisture and fat contents of the chicken nuggets. **Figure 23** depict moisture and fat contents of the nuggets fried in the oils at different repeated frying cycles, respectively.

Frying markedly affected to reduce moisture and increase fat contents of the product. Deep frying is a process of simultaneous heat and mass transfer, in which heat is transferred from the oil to the food, water is evaporated from food, and oil is consequently adsorbed in it (Krokida *et al*., 2000). Moisture content of the nuggets could be maintained more effectively by frying in the 80:20 blended oil ($p<0.05$). Increase frying cycle generally affected to diminish moisture content of the product. Fat content of nuggets obviously increased after frying. By frying in the 80:20 and 60:40 blended oils, fat contents of the products could be lowered ($p<0.05$). This might be supposed since a different physicochemical property of the used oils (Morcira *et al*., 1997; Pinthus and Saguy, 1993). Interestingly, the fat content of nuggets could be maintained through the last cycles by frying with the 80:20 and 60:40 blended oils ($p>0.05$), whereas the fat contents were increased significantly after frying for 4 cycles for the products cooked in the 100:0 and 50:50 blended oils ($p<0.05$). Adsorbed fat amount of foods during frying could adversely affect to quality and shelf–life of fried food by accelerating a chemical deterioration such as lipid oxidation reaction.

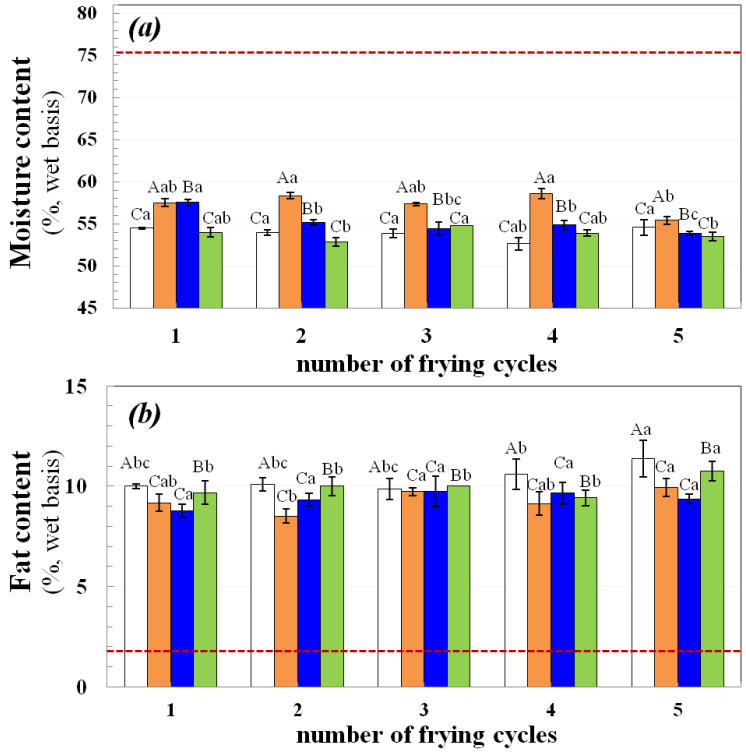

Figure 23 Moisture contents of the chicken nuggets fried in the blended oils at different numbers of frying cycles. The SBO:CO blending ratios were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■).

Means with Std (n=3) were shown. The different capital letters indicate significant difference between means at the same number of frying cycle. The different small letters indicate significant difference between means at the same oil blending ratio.

**The dash lines indicates moisture and fats content of the raw nuggets*

Next, characteristics of French fries cooked in the oils used for several repeated cycles were evaluated, by using the food samples fried in fresh oils as a control. Firstly, the chemical compositions of the raw French fries were determined (see **Table 15**).

Table 15 Chemical composition of raw French fries

chemical composition	content (%, wet basis)
crude protein	2.46 ± 0.19
crude fat	0.06 ± 0.02
moisture	85.00 ± 0.41
ash	1.00 ± 0.03

Figure 24 illustrated moisture and fat contents of the French-fries cooked in the blended oil at different number of repeated frying cycles. The lowest moisture content was found for the French-fries cooked in the 50:50 blended oil (p<0.05). Increasing number of frying cycle affected to diminished moisture content of the French-fries cooked in the 50:50 (60:40) blended oil since the 2nd (3rd) cycle (p<0.05), whereas the moisture content of the food samples cooked in the 100:0 and 80:20 was not affected by the number of frying cycle (p>0.05). Fat content of the French-fries generally tended to increase with number of frying cycle. More adsorbed oil content in potatoes was also observed when frying time was increased (Krokida *et al*., 2000). By cooking in the 80:20 and 60:40 blended oils, the French-fries with lower fat content could be prepared (p<0.05). This tendency was in agreement with the fat content present in the chicken nuggets fried in the blended at these ratios

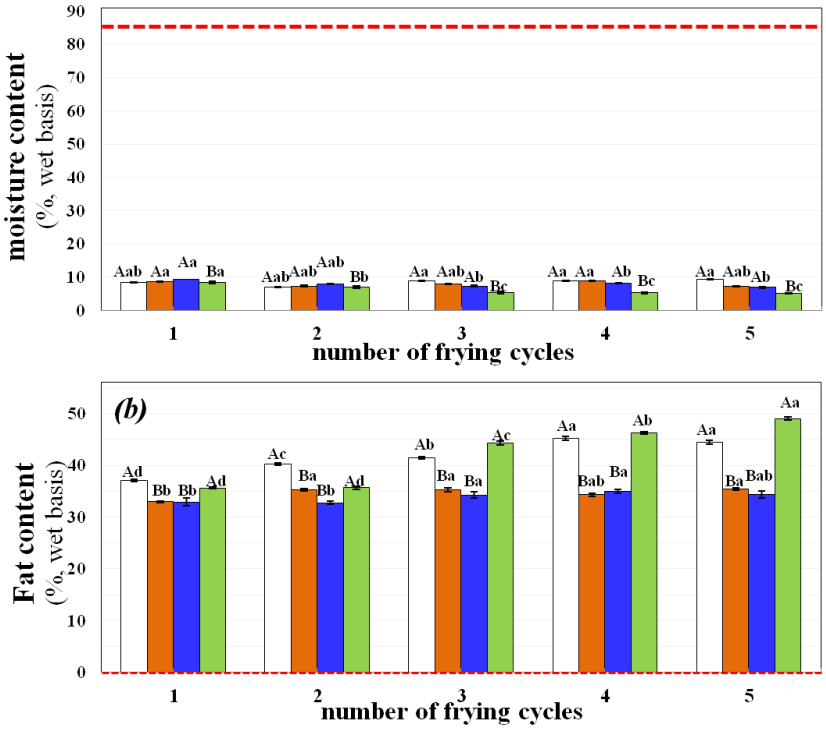

Figure 24 Moisture contents of the French-fries cooked in the blended oils at different numbers of frying cycles. The SBO:CO blending ratios were 100:0 (□), 80:20 (■), 60:40 (■), and 50:50 (■).

Means with Std (n=3) were shown. The different capital letters indicate significant difference between means at the same number of frying cycle. The different small letters indicate significant difference between means at the same oil blending ratio.

**The dash lines indicates moisture and fats content of the raw French-fries.*

To investigate the characteristics of the products fried in the oils used for several repeated cycles, color and texture parameters of the food materials were observed. **Table 16** shows the color parameters of the nugget crusts after frying. Frying affected to reduce lightness of the nugget crusts. By blending with CO, *L** of the fried products could be increased, especially for the products cooked by 60:40 blended oil providing the highest *L** score compared to the others ($p<0.05$). The nuggets cooked in SBO showed the highest redness and yellowness compared to the counterparts fried in other blended oils ($p<0.05$). By increasing the numbers of frying cycles, lightness tended to decrease, whereas redness and yellowness were increased.

Table 16 Color parameters of the crusts of chicken nuggets fried in the blended oils used for several repeated cycles

SBO:CO	number of frying cycle	Color parameters		
		*L**	*a**	*b**
100:0	0	68.81 ± 1.65 Da	1.70 ± 0.12 Ac	29.54 ± 1.98 Abc
	1	62.14 ± 1.85 Dbc	8.22 ± 1.86 Ab	33.37 ± 1.06 Aab
	2	61.76 ± 2.89 Dbc	8.61 ± 1.90 Aab	34.58 ± 1.55 Aab
	3	63.88 ± 1.67 Db	9.45 ± 0.42 Aab	33.66 ± 2.05 Aab
	4	61.40 ± 1.14 Dbc	9.73 ± 0.49 Aab	33.02 ± 0.97 Aab
	5	59.61 ± 1.18 Dc	10.14 ± 0.57 Aa	32.01 ± 2.10 Ab
80:20	0	71.97 ± 0.81 Ba	1.45 ± 0.29 Cd	27.65 ± 1.49 Bb
	1	69.17 ± 0.85 Bb	2.73 ± 0.37 Cc	28.97 ± 0.90 Bb
	2	67.69 ± 1.77 Bb	3.12 ± 0.45 Cbc	28.50 ± 1.46 Bb
	3	67.86 ± 1.15 Bb	3.22 ± 0.19 Cbc	29.66 ± 0.77 Bb
	4	65.61 ± 0.33 Bc	3.59 ± 0.36 Cb	31.93 ± 0.47 Ba
	5	63.89 ± 0.81 Bd	5.03 ± 0.50 Ca	33.07 ± 1.76 Ba
60:40	0	74.21 ± 0.57 Aa	1.46 ± 0.18 BCd	27.32 ± 1.54 Bc
	1	72.51 ± 1.44 Ab	2.66 ± 0.67 BCc	29.81 ± 2.23 Bb
	2	72.14 ± 0.69 Ab	2.61 ± 0.64 BCc	30.09 ± 0.71 Bb
	3	67.14 ± 0.72 Ac	4.05 ± 0.73 BCb	29.18 ± 1.91 Bab
	4	64.48 ± 1.42 Ad	5.18 ± 0.65 BCa	32.24 ± 1.30 Ba
	5	64.17 ± 1.07 Ad	5.50 ± 0.38 BCa	32.18 ± 0.77 Ba
50:50	0	72.02 ± 1.37 Ca	1.15 ± 0.58 Bb	25.26 ± 2.01 Bb
	1	69.49 ± 0.65 Cb	2.20 ± 0.25 Bb	26.85 ± 1.40 Bb
	2	66.37 ± 1.11 Cc	4.13 ± 0.33 Ba	31.22 ± 0.86 Ba
	3	64.15 ± 1.97 Cc	4.97 ± 0.49 Ba	31.20 ± 0.97 Ba
	4	64.24 ± 2.32 Cc	4.96 ± 1.50 Ba	31.15 ± 4.85 Ba
	5	63.99 ± 0.98 Cc	5.03 ± 0.55 Ba	31.84 ± 1.27 Ba

Means ± Sd (*n*=5) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) at a confidential level of 95 %.

Table 17 illustrates color of the French-fries cooked in the blended oils at different number of repeated cycles.

Table 17 Color of the French-fries cooked in the blended oils used for several repeated cycles

SBO:CO	number of frying cycle	Color parameters		
		*L**	*a**	*b**
100:0	1	45.04±0.92Ba	2.00±0.13Ba	19.30±1.27Aa
	2	40.89±1.53Bb	1.96±0.17Ba	18.60±0.47Aa
	3	39.43±1.79Bb	1.94±0.10Ba	18.81±0.70Aa
	4	39.33±1.39Bb	1.93±0.19Ba	18.55±0.64Aa
	5	39.15±0.96Bb	1.84±0.15Ba	18.49±1.05Aa
80:20	1	44.60±1.77Ba	2.04±0.03ABa	19.22±0.30ABa
	2	42.04±1.30Bb	1.97±0.16ABa	19.65±0.56ABa
	3	41.98±1.17Bb	1.95±0.07ABa	19.30±1.24ABa
	4	41.58±1.98Bb	1.96±0.09ABa	19.12±0.62ABa
	5	41.62±1.58Bb	1.96±0.09ABa	18.91±0.76ABa
60:40	1	45.77±2.10Aa	2.02±0.13ABa	19.78±1.66Aa
	2	45.81±1.61Aa	2.04±0.16ABa	19.72±1.20Aa
	3	44.94±0.66Aa	2.02±0.27ABa	19.60±0.86Aa
	4	44.39±2.38Aa	2.05±0.28ABa	19.17±0.96Aa
	5	44.59±3.02Aa	2.03±0.16ABa	19.32±1.82Aa
50:50	1	45.54±0.75Aa	2.08±0.05ABa	19.50±0.51Aa
	2	45.06±0.08Aa	2.02±0.15ABa	19.43±1.13Aa
	3	45.21±1.44Aa	2.04±0.22ABa	19.30±0.14Aa
	4	45.40±1.97Aa	2.08±0.06ABa	19.32±1.27Aa
	5	44.49±2.27Aa	2.00±0.10ABa	19.26±1.26Aa

Means ± Sd (*n*=5) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) at a confidential level of 95 %.

The lower *L** was found for the French-fries cooked in the 100:0 and 80:20 blended oils ($p<0.05$), whereas there was no difference on *a** and *b** values of the products fried in oils with different blending ratios ($p>0.05$). By increasing frying repeated cycles, color of the French-fries was affected. The *L** of French-fries cooked in the 100:0 and 80:20 blended oils reduced significantly after 2nd frying cycle ($p<0.05$). However, the change in *L** with number of frying cycles was not noticeable ($p>0.05$), when French-fries were processed in the 60:40 and 50:50 blended oils. This tendency suggesting to a better color retention of the products when the 60:40 and 50:50 blended oils where used as a heating media to prepare French-fries.

Next, texture profiles of the chicken nuggets fried in the blended oils at different repeated frying cycles were reported as shown in **Table 18**. By using different kinds of oils, texture parameters of the cooked nuggets were affected. The nuggets fried in the 80:20 blended oil exhibited the highest cohesiveness ($p<0.05$). The products fried in the control oil had lower values of hardness and chewiness compared to the counterparts cooked in other blended oils ($p<0.05$). Upon frying in the oils used for several repeated cycles, the cohesiveness of nuggets was significantly changed after the 3rd and 5th cycles, when the 60:40 and 50:50 blended oils were used, respectively ($p<0.05$). Regarding on texture characteristic of the nuggets fried in the control oil, chewiness was decreased significantly after the oil was used for two repeated cycles, whereas the chewiness was not changed with the increased number of frying cycles for the nuggets cooked in other blended oils ($p>0.05$). Cooking process could affect to texture profile of meat products. Gujral *et al.,* (2002) observed the decreased cohesiveness and adhesiveness of meat patties after baking process. The present work suggested that by changing the characteristics of medium oil, texture profile of the fried products were affected.

Table 18 Texture profiles of the nuggets cooked in the blended oils used for several repeated cycles

SBO:CO	number of frying cycle	Texture parameters		
		hardness	cohesiveness	chewiness
100:0	1	10.57 ± 1.06 Ba	0.799 ± 0.003 Ba	12.10 ± 0.47 Ca
	2	10.70 ± 3.09 Ba	0.800 ± 0.021 Ba	10.37 ± 0.02 Cb
	3	11.62 ± 1.95 Ba	0.804 ± 0.022 Ba	7.05 ± 1.00 Cc
	4	11.63 ± 1.81 Ba	0.807 ± 0.008 Ba	6.82 ± 0.94 Cc
	5	12.00 ± 2.10 Ba	0.811 ± 0.002 Ba	6.41 ± 0.12 Cc
80:20	1	10.83 ± 2.44 Aa	0.823 ± 0.006 Aa	10.48 ± 0.24 Aa
	2	11.83 ± 0.54 Aa	0.822 ± 0.001 Aa	10.91 ± 0.14 Aa
	3	12.98 ± 3.92 Aa	0.813 ± 0.009 Aa	11.07 ± 1.03 Aa
	4	13.65 ± 1.07 Aa	0.817 ± 0.008 Aa	11.06 ± 0.74 Aa
	5	13.73 ± 0.08 Aa	0.813 ± 0.001 Aa	10.22 ± 0.14 Aa
60:40	1	11.00 ± 1.75 Aa	0.835 ± 0.005 Aa	10.01 ± 0.40 ABa
	2	12.61 ± 1.30 Aa	0.834 ± 0.006 Aa	10.53 ± 0.59 ABa
	3	13.20 ± 1.48 Aa	0.812 ± 0.004 Ab	10.02 ± 1.20 ABa
	4	13.33 ± 1.38 Aa	0.806 ± 0.005 Ab	9.50 ± 0.57 ABa
	5	13.74 ± 1.39 Aa	0.808 ± 0.011 Ab	8.28 ± 1.25 ABa
50:50	1	11.39 ± 0.02 Aa	0.818 ± 0.011 Ba	11.20 ± 1.44 ABa
	2	12.46 ± 2.29 Aa	0.811 ± 0.004 Bab	11.09 ± 0.07 ABa
	3	13.73 ± 3.38 Aa	0.808 ± 0.008 Bab	10.76 ± 0.03 ABa
	4	14.18 ± 2.78 Aa	0.807 ± 0.009 Bab	10.65 ± 2.00 ABa
	5	14.61 ± 3.81 Aa	0.800 ± 0.004 Bb	9.48 ± 1.40 ABa

Means ± Std (n=3) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) at a confidential level of 95 %.

Table 19 reveals hardness and fracturability of the French fries cooked in the blended oils used for various numbers of repeated frying cycles. Oil blending ratio had no effect on the observed textural parameters of the French-fries (p>0.05). Nonetheless, increase numbers of frying cycle affected to decrease hardness and fracturability of the food materials. By cooking in the 100:0 and 50:50 blended oils, hardness of the potatoes

decreased significantly at the 3rd frying cycle (p<0.05), whereas the hardness of potatoes fried in the 80:20 and 60:40 changed markedly at the 4th frying cycle (p<0.05). Better ability of the French-fries to retain their textural attributes could be observed, when they were cooked in the 60:40 blended oil as suggested by no significant change in fracturability throughout the 5th frying cycle (p>0.05), whereas the samples cooked in the other blended oils possessed significantly lowered fracturability at the last cycle of frying (p<0.05).

Table 19 Texture profiles of French-fries cooked in the blended oils used for several repeated cycles

SBO:CO	number of frying cycle	Texture parameters	
		Hardness	Fracturability (mm)
100:0	1	467.75±22.44ABa	3.049±0.541Aa
	2	454.76±22.14ABab	2.939±0.228Aa
	3	413.10±11.71ABb	2.933±0.503Aa
	4	381.55±19.15ABbc	2.623±0.367Aab
	5	371.13±21.07ABc	2.424±0.214Ab
80:20	1	472.12±10.04Aa	3.092±0.341Aa
	2	456.76±22.21Aab	2.997±0.287Aab
	3	454.54±14.23Aab	3.060±0.088Aab
	4	408.47±23.63Ab	2.767±0.299Aab
	5	399.96±13.76Ab	2.585±0.166Ab
60:40	1	472.86±16.82Aa	3.024±0.167Aa
	2	449.98±20.60Aab	3.040±0.241Aa
	3	438.96±25.00Aab	3.061±0.456Aa
	4	409.96±28.63Ab	2.847±0.264Aa
	5	394.22±21.97Ab	2.878±0.216Aa
50:50	1	466.30±14.26ABa	3.001±0.127Aa
	2	450.48±18.40ABa	2.969±0.154Aa
	3	426.63±11.94ABb	2.802±0.568Aa
	4	383.46±19.19ABbc	2.682±0.385Aab
	5	368.57±28.47ABc	2.341±0.202Ab

Means ± Std (n=5) were shown.

In the same tested parameter, the different capital (small) letters indicate significant difference between means at the same number of frying cycles (blending ratio) at a confidential level of 95 %.

Over all of the results, improvement on thermal stability of SBO could be accomplished via blending with CO at the appropriate ratio, depending on the selected food materials. This was supposed since a reduction in unsaturation degree of SBO as affected by blending with CO. Development on thermal tolerance of the oils led to improve the characteristics of fried food materials, as suggested by decreasing in fat adsorption and retained color and texture attributed along frying process. In the present work, the suitable blending ratio between SBO and CO providing the oils with the greatest thermal tolerance and most desirable fried food characteristics was 60:40.

6. Conclusions

Extraction method influenced oil recovery efficiency and chemical characteristics of the VCO. The highest oil recovery yield could be provided by protease–aided extraction (93.5 %, by using alcalase at 0.3 % v/v and incubation at 60 °C for 120 min) compared to fermentation (74.9 %, by incubation at 30 °C for 36 h), and thermal cycling (79.0 %, by treating with 4 cycles, in which 1 cycle consists of 6 h of freezing at -20 °C, 30 min of incubation at room temperature, and 10 min of heating at 60 °C) techniques. The VCO recovered through enzyme–assisted process possessed higher amount of unsaturated fatty acids compared to the oils extracted by traditional techniques. The VCO recovered through protease–assisted means also showed a greater initial quality as suggested by the lowered PV and FFA. The highest amount of phenolic compounds was found for the VCO prepared by fermentation technique, and the majority phenolic compounds of the VCO were gallic, catechin, vanillic, and *p*-coumaric acids.

Next, VCO was employed to prepare salad dressings, and their physicochemical stability was studied in comparison with the SBO dressings. Influence of TMD at various DE values (9, 12, and 16) and concentrations (0.5, 1.5 and 3 %) on properties of the dressings were also investigated. A comparable colloidal stability between VCO and SBO dressings was observed. Nonetheless, higher oxidative stability of VCO samples than did SBO counterparts was markedly evident. The higher content of phenolic compounds was found for the VCO

dressing. Improvement on dispersibility of the dressings could be accomplished by incorporating TMD at DE 9, especially at increased concentration. TMD could also maintain pH and color changes of the dressings during a storage of 8 weeks. Comparable sensorial acceptability between the VCO and SBO dressings was observed in a presence of 3 % TMD (DE 9). The present study suggested that VCO could be employed to prepare salad dressing with desirable physicochemical stability and enriched phenolic compounds.

Finally, effect of CO blending on frying stability of SBO was studied. SBO was blended with CO at various ratios (SBO:CO mixing ratios of 100:0, 80:20, 60:40, and 50:50), before using to cook chicken nuggets and French-fries at different numbers of repeated frying cycle. Improvement on thermal stability of SBO could be achieved by blending with CO at the appropriate ratio, which was supposed since a reduction in unsaturation degree of SBO. Development on thermal tolerance of the oils led to improve the characteristics of fried food materials, as suggested by decreasing in fat adsorption and retained color and texture attributed along frying process. In the present work, the suitable blending ratio between SBO and CO providing the oils with the greatest thermal tolerance and most desirable fried food characteristics was 60:40.

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8. Future work

Considering on better tolerance against lipid oxidation, higher polarity than other seed oils, and enrichment with health promoting microconstituents, VCO might be a promising candidate for carrying some nutrients to be used in neutraceutical products.

ภาคผนวก

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14th January 2016

Dear Cheetangdee,

MANUSCRIPT IFRJ-2015-175

Your Manuscript entitled "**Characterization of virgin coconut oil (VCO) recovered by different techniques and fruit maturities**" by **Prapun, R., Cheetangdee, N. and Udomrati, S.** has been accepted for publication in the International Food Research Journal. We thank you for your contribution to the International Food Research Journal and encourage you to submit other articles to the Journal.
Please fill and sign the attached forms and return to me to enable us to process your manuscript for publication.

Thank you.

Yours sincerely,

Professor Dr. Son Radu
Editor, International Food Research Journal