Songklanakarin J. Sci. Technol.
41 (3), 513-521, May – Jun. 2019

http://www.sjst.psu.ac.th

Original Article

Effect of chemical degumming process on physicochemical properties of red palm oil

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Received: 25 July 2017; Revised: 22 November 2017; Accepted: 22 December 2017

Abstract

Red palm oil is of high nutrition value and sells at high prices, but a proper technique, which is of importance with regard to industrial production, is not available for the Thai producer yet. This study determined the proper processing condition and found that the optimal condition was acid degumming with citric and phosphoric acids at 90°C for 25 min with continuous agitation. Water degumming followed the acid degumming, and it was carried out by adding 5% (w/w) water and cooling the oil down to 35°C before centrifuging to remove the gums. The excess of free fatty acids was removed by using 7% NaOH. The resulting red palm oil had chemical properties within the product standards. The developed technique is simple, and would be beneficial for both small-scale and large-scale producers in Thailand.

Keywords: acid degumming, water degumming, red palm oil, phosphorus elimination

1. Introduction

Red palm oil is an oil that is high in nutrition compared to other commercial edible oils since it does not pass through various processes such as hydrogenation, refining process, bleaching process, deodorizing process, etc. (Foo, 2012). These processes, especially refining process and bleaching process, cause 60–80% carotenoid reduction, and 10–35% vitamin E and sterol reduction (Avidi, 2003). The remaining compounds in red palm oil are antioxidants that prevent oxidation of the oil; enhance immunity; protect; and prevent diseases such as cancer, heart disease, etc. (Nagendran, Unnithan, Choo, & Kalyana, 2000). In addition, red palm oil does not contain transfats, so it can reduce the risk of coronary heart disease (Khatoon & Reddy, 2005).

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According to the standards for edible oil, phosphorus and free fatty acid contents should not exceed 10 mg/kg and 0.6%, respectively (Codex Alimentarius International Food Standards, 1999). To produce red palm oil, most of the phosphatides and free fatty acids have to be removed from crude palm oil. Presence of these impurities results in darkening, precipitation, and rancidity, which shorten the shelf life of oils. Phosphatides, the major contaminants in crude palm oil, are composed of non-hydratable phosphatides which consist mainly of the calcium and magnesium salts of phosphatidic acid and phosphatidyl ethanolamine, and hydratable compounds. Removal of the nonhydratable portion can be achieved by acid degumming which dissolves nonhydratable phosphatides by use of phosphoric acid and/or citric acid at 85–90°C, whereas hydratable phosphatides can be removed by using the water degumming process (Szydlowska-Czerniak, 2007). Other techniques such as membrane filter degumming can be used to remove phospholipids from crude oil. However, this technique removes not only the phosphatides but also the carotenoids dissolved in the oil (Ong, Fakhru'l-Razi, Baharin, & Hassan,

1999). Degumming by using the phospholipases-enzyme process encourages the formation of free fatty acids (Soe & Turner, 2012).

Degumming of soybean, sunflower, and canola oils has been previously reported (Al-Kahtani, Hanna, Nash, Frankel, & Kwolek, 1984; Jung, Yoon, & Min, 1989; Racicot & Handel, 1983; Smiles, Kakud, & MacDonald, 1988). In general, the amount of gum in the oil is related to the type and quality of the oil. However, there is limited data on the optimal conditions for the degumming process of crude palm oil. The proper conditions for the production of red palm oil from the crude palm oil produced in Thailand have never been reported. This research study aimed to produce the unrefined red palm oil by using a combination of water and acid degumming processes. Further, the caustic treatment was then applied to attain a free fatty acid value within the product standards. The optimal conditions, depending on the quality of the crude oil, for the degumming process and free fatty acid elimination were determined. The proper treatment would keep carotenoid loss to a minimum, optimize the use of chemical reagents, and reduce the refined waste load. The simple and economical process obtained here would benefit producers, and help popularize the novel healthy edible oil in the Thai market.

2. Materials and Methods

2.1 Materials

Crude palm oil was provided by Langsuan Estate Cooperative, Chumporn province. The chemicals used in the experiments were either analytical or HPLC grade.

2.2 Degumming and acid neutralizing processes

2.2.1 Acid degumming process

The acid degumming procedure was carried out by following the method of Raviyan, Srigalung, and Sroynak (2008), with modification. The crude palm oil samples were heated to 70°C, 80°C, 90°C, and 100°C, and 0.02% (v/v) of 20% citric acid and 0.08% (v/v) of 75% phosphoric acid were added, with continuous stirring at 200 rpm for 15 minutes, 20 min, and 25 minutes. Then, the mixture was centrifuged at 6,000 rpm for 15 min to separate the gum. Color (L*, a*, b* system, Minolta Colorimeter CR-400, Konica, Osaka, Japan), viscosity (Brookfield-Programmable Viscometer: Model LVDV II+, Germany), free fatty acid value (Association of Official Analytical Chemists [AOAC], 2000), DPPH-free radical scavenging activity (FRSA) (Rossi, Alamprese, & Ratti, 2007), and carotenoid content (Ribeiro, Chu, Ichikawa, & Nakajima, 2008) were determined to identify the optimal degumming condition.

2.2.2 Water degumming process

The oil degummed by the optimal condition was used to determine the optimal condition for water degumming. The 1%, 2%, 3%, 4%, or 5% distilled water was gradually added to the preheated oil samples (90°C) during cooling down to 25°C, 30°C, 35°C, 40°C, 45°C, or 50°C. The oil samples were maintained at the designated temperature for 15 minutes with continuous stirring at 6,000 rpm. Then, the oil was centrifuged for 15 minutes at 6,000 rpm to separate the hydratable phosphatides. The phosphorus (AOAC, 2000) and free fatty acid contents (AOAC, 2000) of the obtained oil samples were determined to define the optimal condition.

2.2.3 Alkali neutralization

The oil samples prepared according to the optimal water degumming condition obtained were neutralized. The proper quantity of NaOH used in the alkali neutralization was calculated according to Equation (1) and Equation (2), and it was gradually added to the samples while stirring at 6,000 rpm for 0.5 minutes at the selected cooling temperature. The developed soap stock was separated from the oil by centrifugation at 6,000 rpm for 15 minutes. Then, 10–20% (v/v) of 90°C water was added to the oil samples, and the mixture was lightly shaken before centrifuging at 6,000 rpm for 10 minutes to separate the residual soap stock. The oil samples were vacuum dried at 50°C, 150 mmHg, until the moisture content values were less than 0.1%. The samples were then kept in a cold place for further analysis.

The theoretical quantity of NaOH used in the alkaline treatment is based on the ratio of the molecular weights to oleic acid. This factor was determined as follows (O'Brien, 2009):

$$\text{Factor} = \frac{\text{NaOH molecular weight}}{\text{Oleic fatty acid molecular weight}}$$

$$= \frac{40}{282} = 0.142 \qquad (1)$$

Thus, the formula for caustic treatment is as follows (% Excess treatment of palm oil is 0.02):

$$\%\ \text{Treatment} = \frac{(\%\ \text{FFA} \times 0.142) + \%\ \text{Excess} + \text{Acid addition}}{\%\ \text{NaOH in caustic}} \qquad (2)$$

2.3 Physicochemical analysis of red palm oil

2.3.1 Color

The samples were measured for color characterization in the CIE (L*, a*, b*) system by using a Minolta Colorimeter CR-400 (Konica, Osaka, Japan). The oil samples were placed in a 1 inch cell, and the color was determined at 30°C.

2.3.2 Viscosity

The viscosity of the oil sample was determined by a Brookfield viscometer (Model LVDV-II+, USA). The measurement was operated at a constant shear rate of 200 rpm at 35°C using spindle S28.

2.3.3 Capillary melting points

A few crystals of the oil samples were placed in a closed capillary tube. The tube and a thermometer were placed in a water bath which was heated slowly and evenly. The

melting temperature was observed (AOAC, 2000; method Cc 3-25).

2.3.4 Smoking point

About 150 ml of the oil was heated. The smoke point was noted when it started smoking (American Oil Chemists' Society, 2002; method Cc 9a-48).

2.3.5 Specific gravity

The sample was melted, filtered through a filter paper, cooled to 30°C, and the specific gravity determined by using a pycnometer (AOAC, 2000; method 920.212).

2.3.6 Chemical analyses

Standard methods were used to determine the following properties: phosphorus content (AOAC, 2000), free fatty acid content (FFA) (method: Ca 5a-40), peroxide value (PV) (method: Cd 8-53), DPPH-free radical scavenging activity (FRSA) (Kim, 2005), carotenoid (Ribeiro *et al.*, 2008), saponification number, unsaponification number and Iodine value (American Oil Chemists' Society, 2002).

2.3.7 Determination of fatty acid composition

Fatty acid methyl esters of the oil samples were prepared by interesterification, according to the American Oil Chemists' Society (2002) Method: Ce 1-62. Fatty acid methyl esters were analyzed on a 7890A series gas chromatograph (Agilent Technologies), equipped with a hydrogen flame ionization detector (FID) and a fused silica capillary column (HP-5MS 30 mx0.25 mm IDx0.25 μm film thickness). The reference standard for the fatty acid methyl esters was purchased from Supelco Inc.

2.4 Consumer acceptance test

Oil samples stored at room temperature were presented to 70 panelists to evaluate appearance, clearness, colour, odor, and overall acceptability using 9-point hedonic scale (Resurreccion, 1998). The experimental design was randomized complete block design. The panelists sniffed coffee between evaluations of each sample to clean the leftover of previous aroma in their nasal cavity.

2.5 Statistical analysis

Analysis of variance (ANOVA) was carried out using SPSS Version 11.5 for Windows (SPSS Inc., USA), and the determination of significant differences among means was done by Duncan's multiple range tests ($P \leq 0.05$). All data were the means of triplicate determinations with standard deviations (means ± standard deviation).

3. Results and Discussion

3.1 Physicochemical properties of crude palm oil

The physicochemical properties of the crude palm oil samples were similar to those previously reported in related literature (Table 1). The free fatty acid and phosphorus contents of the oil samples were high. However, it contained moderate amounts of carotenoids that are valuable nutrients and powerful antioxidants. If the excess phosphatides and fatty acids could be removed without losing significant amounts of carotenoids, then the oil would be a potential raw material for making good quality red palm oil.

Table 1. Physicochemical properties of crude palm oil

Crude palm oil properties	Observed in this work	Reported by Morad (1995)	Reported by Standards Malaysia (2007)
Color L*	28.44±1.53	-	
a*	8.14±1.09	-	
b*	2.14±1.13	-	
Melting point (°C)	37.5±0.01	37.5	33.8-39.2
Free fatty acid (%)	3.98±1.43	2–5	
Phosphorus content (mg/kg)	121.18±0.01	10–20	
Saponification number (mg KOH/g)	196.3±0.11	196	194-205
Unsaponification number (%)	0.59±0.11	0.5	0.19-0.44
Carotenoid (mg/kg)	593.71±0.01	500–700	474-689
Iodine value (Wijs)	50.81±0.01	-	50.4-53.7

Notes: The values presented are the means and the standard deviation of triplicate analysis.

3.2 Production of red palm oil

3.2.1 Acid degumming process

A solution of citric and phosphoric acids is normally used in the degumming process in the palm oil industry in Thailand because both the acids are food grade additives that become well dispersed in the oil and are strong enough to bind with the divalent metal ions in the gum. As the goal of this study was to apply the current manufacturing procedure to red palm oil production, a solution of phosphoric and citric acids at the concentration generally used in the industry was applied in this study. The temperature and the reaction time were evaluated to determine the minimum degumming conditions. Excess heat and time can cause degradation of carotenoids and oxidation of lipids, whereas inadequate heat treatment would affect degumming efficiency. Therefore, selection of the most suitable temperature and time would play an important part in producing good quality red palm oil.

Figure 1 shows that the acid degumming temperature and the reaction time statistically ($P<0.05$) affected the color of the oil. When the temperature and the time increased, the L* and the a* values decreased. This indicates that higher temperatures and longer heating times cause the oil to become darker. The fading of the red color resulted partially from the changing structure of the carotenoids from all-*trans* double bonds to partial *cis* when exposed to heat (Chen & Huang, 1998). At the same time, the increase in the b* value indicates that the oil became yellowish brown as a result of decomposition of the carotenoids. Appearance of the crude palm oil and the degummed crude oil were as shown in Figure 2.

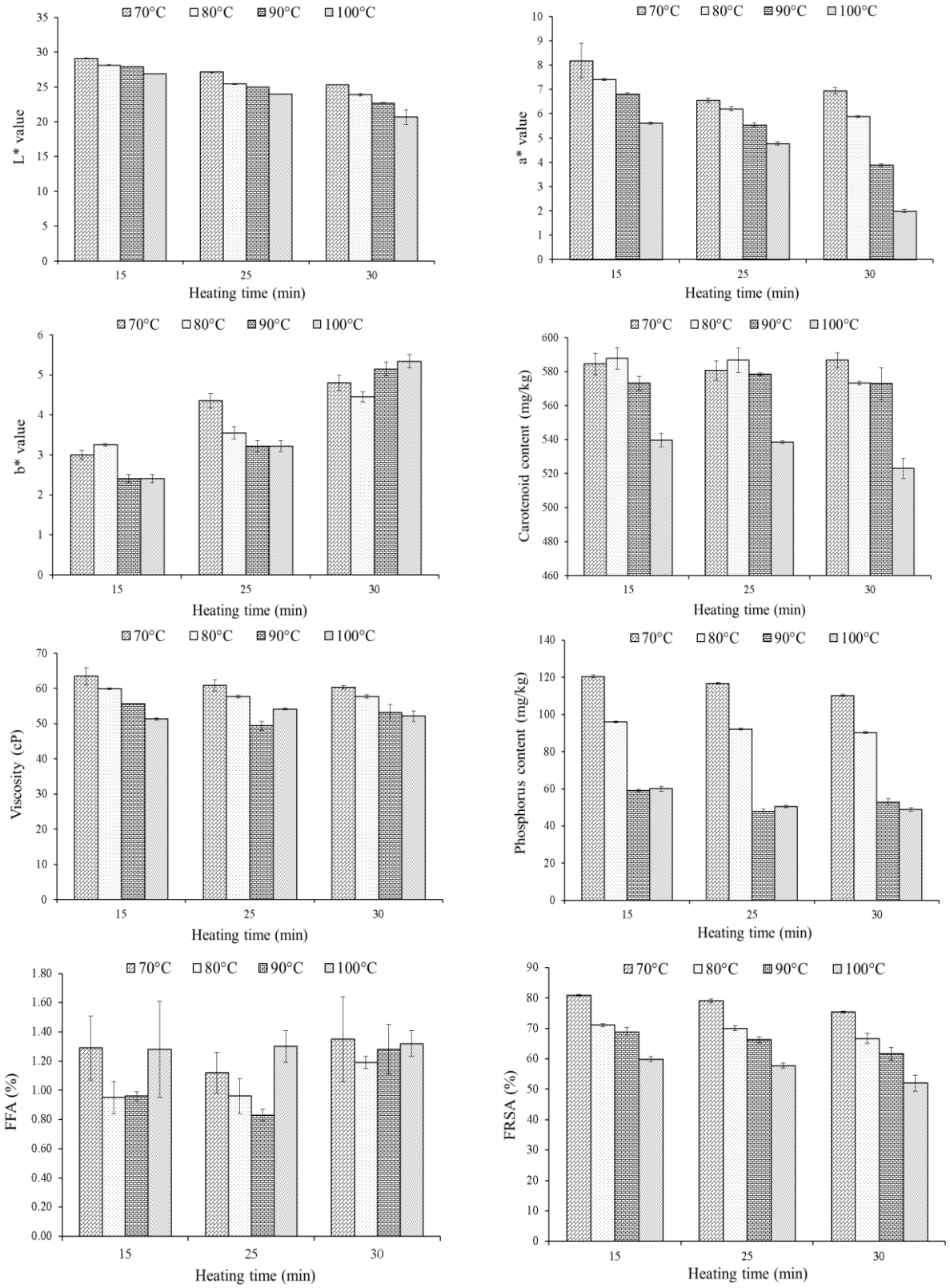

Figure 1. The L* value, a* value, b* value, carotenoids contents, viscosity values, phosphorus contents, free fatty acid contents, and DPPH-free radical scavenging activity of the degummed oil samples obtained under various acid degumming conditions.

(a) **(b)**

Figure 2. Appearance of oil samples; (a) crude palm oil (b) degummed oil

The degradation of carotenoids (Figure 1) was consistent with the color observation (Figure 2). The residual carotenoids, 500–700 mg/kg, were still high enough to produce red palm oil; however, these levels were rather dependent on the initial oil quality.

The viscosity value of an oil can be roughly considered as indicating the degumming efficiency as greater amounts of gum relates to higher viscosity. Figure 1 illustrates that lower viscosity, or better elimination of the gum, was achieved when the degumming temperature and time were increased. Degumming at 90°C for 25 minutes yielded the lowest viscosity, or the maximum removal of the gum.

The results of the residual phosphorus (Figure 1) confirmed the viscosity results. Temperature is significantly important for removal of phosphorus from palm oil. Degumming at higher temperatures and for longer times resulted in greater reduction of the phosphorus content. The overall results suggest that the optimal degumming conditions would be 90°C, 25 minutes, where the phospholipid content would reduce from 121.18 mg/kg to 47.85 mg/kg. Carr (1978) reported that degumming of oil at high temperatures is less successful because the solubility of phosphatides in the oil increases. On the other hand, increased oil viscosity at lower temperatures causes more difficulty as regards phosphatide removal.

Heating at 100°C contributed to the highest amount of free fatty acids (Figure 1). The reason is that heat treatment leads to lipid oxidation which yields free fatty acids (Lee, Chung, & Lee, 2007). High heat also causes rapid degradation of carotenoids (Figure 1) which possess antioxidant activity. The results with regard to the free fatty acids confirmed the other findings that the proper degumming conditions consist of using a temperature of 90°C for 25 minutes with continuous agitation.

As expected, the DPPH-free radical scavenging activities of the degummed oil samples were observed to have decreased ($P \leq 0.05$) with the heating temperatures and the times (Figure 1). The decrease in the scavenging activity was found to be in good correlation with the decrease in carotenoids when the heating time was 30 minutes (Figure 1). The reason, as described by Lee *et al.* (2007), is that at short periods of heating, the free radical scavenging ability is high because the residual antioxidants in the heating oil are high. If the heating time is increased, the value of the free radical scavenging ability would decrease as a result of the decreasing amount of antioxidants, and this would increase the amount of free radicals in the oil.

The results of the overall physicochemical and functional properties suggest that the proper acid degumming process for the crude palm oil sample is heating the oil at 90°C for 25 min. The nonhydratable gums, such as calcium and magnesium salts of phosphatidic acid and phosphatidyl ethanolamine, are converted into hydratable forms (Ringers & Segers, 1977), which can be further removed by centrifugation. Though, in this study, acid degumming could noticeably decrease the phosphorus content from 121.18 mg/kg to 47.85 mg/kg, the amount was still more than 10 mg/kg as required by the product standards (Codex Alimentarius International Food Standards, 1999). High amounts of residual phosphorus would contribute to cloudy appearance, less sensory acceptance, and short shelf life of the oil. Further, the water degumming process was then applied to attain a phosphorus value within the product standards.

3.2.2 Water degumming process

Adding water promotes dissolving of the remaining free phosphatidic acid and phosphatidyl ethanolamine in the oil. The dissolved phosphatide was cooled down to be converted to the agglomerated form before further removing the gum by centrifugal action (Ringers & Segers, 1977). The amount of the residual phosphorus (Figure 3) indicates the effect of cooling temperature on water degumming efficiency. The best cooling temperature was found to be 35°C, at which the phosphorus content was reduced from 47.85 mg/kg to 7.81 mg/kg. The reason for the high cooling temperatures (45°C and 50°C) delivering lower degumming efficiency was probably that the agglomeration of the liberated phosphatides could develop at lesser amounts. In contrast, the dissociation of the free phosphatidic acid and phosphatidyl ethanolamine could not be completed at low cooling temperatures.

The residual phosphorus depends mainly on the initial oil quality. If the level of phosphorus does not exceed the product standards, further water degumming is not required. In this study, the remaining phosphorus was found to exceed the standards. Thus, analysis for the proper amount of water was further carried out by using the proper cooling temperature of 35°C. It has been reported that the amount of water substantially affects the degree of phosphate hydration, which controls the dissociation of free phosphatidic acid and phosphatidyl ethanolamine (Ringers & Segers, 1977). Figure 4 demonstrates that 5% (w/w) of water was adequate to reduce the residual phosphorus to 3.61 mg/kg, which is within the requirement of the product standards.

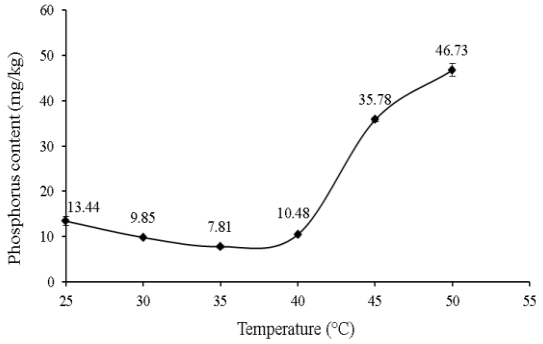

Figure 3. The effect of the water degumming temperature on the phosphorus content of the oil samples.

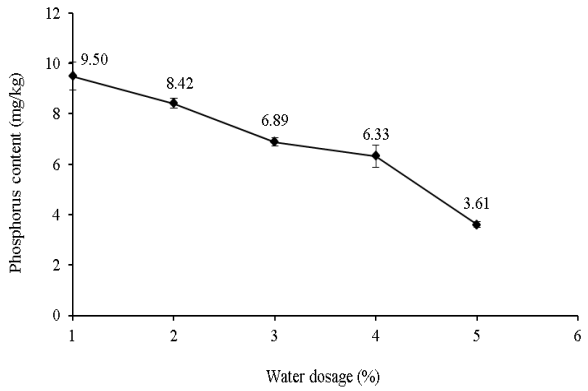

Figure 4. The effect of water dosage on the phosphorus content of the oils.

3.2.3 Alkali neutralization

The free fatty acids present in the oil were partially eliminated by neutralization with NaOH solution. The added alkali reacts with the free fatty acids to form soap stock. The optimal amount of the alkali was determined to minimize the saponification of the oil and prevent the promotion of emulsions during separation. Table 2 reveals that using 7.0% NaOH could reduce the level of the free fatty acids to below the maximum amount of 0.6% as required by the product standards. This strength of the NaOH solution also provided the highest amount of the residual carotenoids. This strength of NaOH was found to agree with the findings of previous reports that the concentrations of NaOH typically used were in the range of 6–9%, with the suitable amounts falling in the range of 7.29–8.0%. In principle, the proper concentration of NaOH could be estimated by calculating the proportion of the molecular weight of NaOH to the molecular weight of oleic acid (O'Brien, 2009).

Table 2. Free fatty acids and carotenoid contents of neutralized oils at various concentrations of NaOH solution.

NaOH concentration (%)	Free fatty acid (%)	Carotenoid (mg/kg)
6.0	0.60^{b}±0.04	277.72^{a}±5.04
7.0	0.54^{b}±0.04	265.64^{b}±2.04
7.5	0.58^{b}±0.08	257.40^{c}±4.11
8.0	0.60^{b}±0.04	262.51^{b}±3.28
9.0	0.75^{a}±0.04	258.30^{bc}±3.59

Notes: The values presented are the means and the standard deviations of triplicate analysis. The mean values within the same column followed by different subscript letters are significantly (P≤0.05) different.

3.3 Physicochemical properties and fatty acid compositions of developed and commercial red palm oils

Red palm oil produced under the optimal conditions visually appeared as bright red in color. The color attributes indicate that the developed product was less in lightness but more intense in its red color as compared to commercial red palm oil (Figure 5). The richer redness of the developed product is mainly associated with the higher carotenoid content. The viscosity, melting point, smoking point, and specific gravity of the studied red palm oil were rather high as compared to those of the commercial red palm oil. This is because the commercial red palm oil was prepared from the blending of 40% red palm olein and 60% canola oil. The different chemical compositions of the oils would result in different physical properties. In general, oils with higher content of saturated fatty acids have higher viscosity and melting point. Nevertheless, the resulting red palm oil had chemical properties within the standard of edible oil, as presented in Table 3.

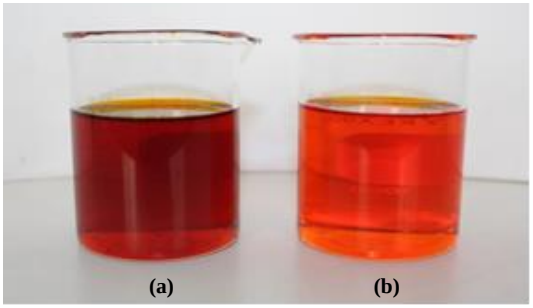

Figure 5. Appearance of the oil samples; (a) developed red palm oil (b) commercial red palm oil

Table 3. Physicochemical properties of the developed red palm oil and commercial red palm oil.

Physicochemical property	Developed red palm oil	Commercial red palm oil[1]	Standard of edible oil [Codex Alimentarius International Food Standards (1999)]
Physical properties			
Color L*	28.62^{b}±0.80	39.36^{a}±0.04	-
a*	10.61^{a}±0.07	5.36^{b}±0.07	-
b*	24.79^{a}±1.37	13.51^{b}±0.04	-
Viscosity (cP)	55.50^{a}±0.30	51.13^{b}±0.28	-
Melting point (°C)	36.15^{a}±1.13	23.25^{b}±0.60	35–45
Smoke point (°C)	215.7^{a}±0.73	205.1^{b}±0.73	-
Specificgravity (30°C)	0.923^{a}±1.54	0.921^{b}±1.60	-
Iodine value (g I2/100g)	55.98±0.31	57.89±0.00	-
Chemical properties			
Free fatty Acids (%)	0.54^{a}±0.04	0.17^{b}±0.02	≤ 0.6
Phosphorus content (mg/kg)	3.72^{a}±0.51	1.40^{b}±0.17	≤ 10
Peroxide value (meq.O_2/kg)	8.30^{a}±0.11	2.71^{b}±0.29	-
Sponification (mg KOH/g)	183.30^{b}±0.58	190.14^{a}±062	190–209
Unsponifiable matter (g/100g)	0.28^{b}±0.19	0.81^{a}±0.36	≤12
Carotenoid content (mg/kg)	587.50^{a}±7.13	457.87^{b}±7.18	-

Notes: [1]The commercial red palm oil was prepared from 40% red palm olein and 60% canola oil. The values presented were the means and the standard deviations of triplicate analysis. The mean values within the same column followed by different subscript letters are significantly (P≤0.05) different.

The quantities of saturated, monounsaturated, and polyunsaturated fatty acids in the oil sample were calculated by summation each type of fatty acids. The crude, degummed and red palm oils contained the similar amount of saturated, monounsaturated, and polyunsaturated fatty acids (Table 4). This indicated that the selected acid degumming temperature and the reaction time as well as the strength of the caustic solution did not affect the fatty acid composition of the oil samples. Besides, the amounts of saturated, monounsaturated, and polyunsaturated fatty acids of the resulting red palm oil were within the standard of edible oil of 43.3–55.5%, 36–44%, and 9–12%, respectively (Codex Alimentarius International Food Standards, 1999).

Table 4. Fatty acid composition of oil samples.

Fatty acids	Crude palm oil (observed in this work)	Crude palm oil (reported by Malaysian Standard MS816:2007)	Degummed oil (observed in this work)	Red palm oil (observed in this work)
Saturated fatty acid (% w/w)				
Lauric acid (C12:0)	0.46	0.0-0.5	0.44	0.42
Myristic acid (C14:0)	0.99	0.9-1.5	1.21	1.40
Palmitic acid (C16:0)	43.07	39.2-45.8	42.02	42.02
Stearic acid (C18:0)	4.62	3.7-5.4	4.39	4.29
Arachidic acid (C20:0)	0.34	0.0-0.5	0.30	0.31
Behenic acid (C22:0)	0.04	_	0.05	0.04
Lignoceric acid (C24:0)	0.04	_	0.07	0.04
Monounsaturated fatty acid (% w/w)				
Palmitoleic acid (C16:1n7)	0.19	0.0-0.4	0.18	0.12
Cis-9-Oleic acid (C18:1n9c)	38.29	37.4-44.1	39.06	39.77
Cis-11-Eicosenoic acid (C20:1n11)	0.10	_	0.10	0.10
Polyunsaturated fatty acid (% w/w)				
Cis-9,12-Linoleic acid (C18:2n6)	10.49	8.7-12.5	10.51	11.52
α- Linolenic acid (C18:3n3)	0.22	0.0-0.6	0.33	0.22
SFA (% w/w)	49.56	47–54	48.48	48.52
MUFA (% w/w)	38.58	37–41	39.34	39.99
PUFA (% w/w)	10.71	9–11	10.84	11.74

3.4 Consumer acceptance

Although sensory acceptance of the red palm oil sample is not as high as that of the commercial sample (Table 5), but the data is useful information for developing a commercial product. The panelists rated all of the sensory characteristics of the studied red palm oil from like slightly to like moderately, except the odor. This is because the unrefined red palm oil has strong scent that the panelists are not familiar.

Table 5. Sensory evaluation of developed red palm oil and commercial red palm oil.

Attribution	Sample	
	Red palm oil	Commercial red palm oil
Appearances	6.68^{b}±1.10	7.76^{a}±1.62
Clearness	6.51^{b}±1.63	8.16^{a}±1.38
Color	7.12^{b}±1.57	8.81^{a}±1.09
Odor	4.21^{b}±1.28	7.96^{a}±1.60
Overall liking	6.03^{b}±1.14	8.11^{a}±1.40

Notes: [1]The commercial red palm oil was prepared from 40% red palm olein and 60% canola oil. The mean values within each column followed by different subscript letters (a, b, c, etc) were significantly different ($P \leq 0.05$).

As such, a feasible approach to reduce the distinct odor and increase overall acceptability of red palm oil is blending the oil with other odorless cooking oil, like rice bran and soybean oils. Furthermore, the optimized process parameters that minimize the undesirable flavor need to be determined.

3.5 Overall discussion

Carotenoids content is important in terms of nutritional quality of red palm oil. However, high content of carotenoids could affect the oil quality during storage. Studies on soybean and rapeseed oils revealed that carotenoids demonstrate both antioxidant and prooxidant activities depending on the oil system (Haila & Heinonen, 1994; Lee, Ozcelik, & Min, 2003). At high concentration of oxygen, carotenoids increase oil oxidation that caused by the photosensitized oxidation (Haila & Heinonen, 1994). However, carotenoids could decrease the oxidation of soybean oil by $^{1}O_2$ quenching when the oil is exposed to the light (Lee & Min, 1988).

For the autoxidation that triplet oxygen ($^{3}O_2$) reacts with lipid alkyl radical which forms peroxy radical. The lipid peroxy radical then reacts with hydrogen to form hydroperoxide in which decomposition of the hydroperoxide yields off-flavor substances. It was reported that carotenoids act as antioxidant when the oil is kept at low oxygen concentration. This is because a carotene radical could successfully react with lipid peroxy radicals and form nonradical products. In contrast, carotenoids act as prooxidant at high oxygen concentration system because a lipid peroxy radical could be added to β-carotene and produce carotene peroxy radical (Burto & Ingold, 1984). Carotene peroxy radical then reacts with $^{3}O_2$ and with lipid molecules, and yields lipid alkyl radicals, which promote the sequence reaction of lipid oxidation (Iannone, Rota, Bergamini, Tomasi, & Canfield, 1998).

It could be concluded from the previous works that carotenoids could promote autoxidation and photosensitized oxidation when keeping the oil under high concentration of oxygen. Thus, oxidation of the developed red palm oil could be minimized by excluding oxygen. In addition, other causes that would accelerate rates for the formation of lipid peroxy radical and hydroperoxide such as heat, light, metals and oxidized compounds should be prevented.

4. Conclusions

The optimal condition for production of the unrefined red palm oil was found to be, firstly, acid degumming with citric and phosphoric acid solutions at 90°C for 25 min, followed by water degumming using 5% (w/w) water and cooling temperature of 35°C. The excess free fatty acids were reduced by using 7% NaOH. This suggested procedure could produce red palm oil with the chemical properties required by the product standards. The developed technique is simple, and it contributes to creating a desirable product in that its properties are comparable to those of the commercial product. The processing conditions obtained here will be beneficial for both small-scale and large-scale producers in Thailand.

References

Al-Kahtani, H. A. M, Hanna, M. A., Nash, A. M., Frankel, E. N., & Kwolek, W. F. (1984). Degumming soybean oil from fresh and damaged beans with surface-active compounds. *Journal of the America Oil Chemists' Society, 61*(5), 921-923. doi:10.1007/BF02542167

American Oil Chemists' Society. (1997). *Official methods and recommended practice* (5th ed.). Urbana, IL: AOCS Press.

Association of Official Analytical Chemists. (2000). Official methods of analysis of analysis (17th ed.). Washington, DC: Author.

Avidi, S. L. (2003). Tocol-derived minor constituents in selected plant seed oils. *Journal of the America Oil Chemists' Society, 80*, 327-333. doi:10.1007/s11746-003-0698-9

Burton, G. W., & Ingold, K. U. (1984). β-Carotene: An unusual type of lipid antioxidant. *Science*, *224*, 569–573. doi:10.1126/science.6710156.

Carr, R. A. (1976). Degumming and refining practices in the U.S.A. *Journal of the America Oil Chemists' Society*, *53*, 332-333.

Chen, B. H., & Huang, J. H. (1998). Degradation and isomerization of chlorophyll a and β-carotene as affected by various heating and illumination treatments. *Food Chemistry*, *62*, 299-307.

Codex Alimentarius International Food Standards. (1999). *Standard for named vegetable oils: CODEX STAN 210-1999*. Geneva, Switzerland: Author.

De, B. K., & Patel, J. D. (2010). Effect of different degumming processes and some nontraditional neutralizing agent on refining of rice bran oil. *Journal of Oleo Science*, *59*(3), 121-125. doi:10.5650/jos.59.121.

Foo, S. P. (2012). Red palm oil and phytonutrients. *Proceeding of the 17th International Oil Palm Conference*. Cartagena, Colombia.

Haila, K., & Heinonen, M. (1994). Action of β-carotene on purified rapeseed oil during light storage. *Food Science and Technology*, *27*, 573–577. doi:10.1006/fstl.1994.1112

Iannone, A., Rota, C., Bergamini, S., Tomasi, A., & Canfield, L. M. (1998). Antioxidant activity of carotenoids: An electron-spin resonance study on β-carotene and lutein interaction with free radicals generated in a chemical system. *Journal of Biochemical and Molecular Toxicology, 12,* 299–304. doi:10.1002/(SICI)1099-0461(1998)12:5<299::AID-JBT6>3.0.CO;2-G.

Jung, M. Y., Yoon, S. H., & Min, D. B. (1989). Effects of processing steps on the contents of minor compounds and oxidation of soybean oil. *Journal of the America Oil Chemists' Society, 66*(l), 118-20. doi:10.1007/BF02661798

Khatoon, S., & Reddy, S. R. Y. (2005). Plastic fats with zero-*trans* fatty acids by interesterification of mango, mahua and palm oils. *European Journal of Lipid Science and Technology, 107*, 786-791. doi:10.1002/ejlt.200501210

Kim, S. J. (2005). Radical scavenging capacity and antioxidant activity of the E vitamer fraction in rice bran. *Journal of Food Science*, 70, 208-213. doi:10.1111/j.1365-2621.2005

Lee, J. H., Ozcelik, B., & Min, D. B. (2003). Electron donation mechanisms of β-carotene as a free radical scavenger. *Journal of Food Science*, 68, 861–865. doi:10.1111/j.1365-2621.2003.tb08256.x.

Lee, J. M., Chung, P. S., & Lee, J. H. (2007). Development of a method predicting the oxidative stability of edible oils using 2, 2-diphenyl-1-picrylhydrazyl (DPPH). *Journal of Food Chemistry*, *103*, 662-669. doi:10.1016/j.foodchem.2006.07.052

Lee, E. C., & Min, D. B. (1988). Quenching mechanism of beta-carotene on the chlorophyll-sensitized photooxidation of soybean oil. *Journal of Food Science*, *53*, 1894–1895. doi:10.1021/ja01024a061.

Mendez, E., Sanhueza, J., Speisky, H., & Valenzuela, A. (1996). Validation of the rancimat test for the assessment of the relative stability of fish oils. *Journal of the American Oil Chemists' Society*, *73*, 1033-1037. doi:10.1007/BF02523412

Morad, N. A. (1995). The physical properties of palm oil mixtures for design of process equipment (Doctoral thesis, University of Leeds, Leeds, England). Retrieved from https://www.google.com.pk/search?q=The+physical+properties+of+palm+oil+mixtures+for+design+of+%09process+equipment+&oq

Nagendran, B., Unnithan, U. R., Choo, Y. M., & Kalyana, S. (2000). Characteristics of red palm oil, a carotene-and vitamin E-rich refined oil for food uses. *Food and Nutrition Bulletin, 21*(2), 189-194. doi:10.1177/156482650002100213

O'Brien, R. D. (2009). *Fat and oils/formulating and processing for applications* (3rd ed.). Boca Raton, FL: CRC Press.

Ong, K. K., Fakhru'l-Razi, A., Baharin, B. S., & Hassan, M. A. (1999). Degumming of crude palm oil by membrane filtration. *Artificial Cells, Blood Substitutes, and Biotechnology, 27*(5-6), 381-385. doi:10.3109/10731199909117707.

Racicot, L. D., & Handel, A. P. (1983). Degumming of soybean oil: Quantitative analysis of phospholipids in crude and degummed oil. *Journal of the America Oil Chemists' Society, 60*(6), 1098-1101. doi:10.1007/BF02671333

Raviyan, P., & Soinak, K. K. (2012). *Extraction of vitamin E from palm fatty acid distillate by sequential cooling hexane* (US Patent No. 20120130094 A1). Retrieved from http://www.google.com/patents/US20120130094

Resurreccion, A. V. A. (1998). *Consumer sensory testing for product development*. Montgomery, MD: Aspen Publication.

Ribeiro, H. S., Chu, B. S., Ichikawa, S., & Nakajima, M. (2008). Preparation of nanodispersions containing β-carotene by solvent displacement method. *Food Hydrocolloids, 22*, 12-17. doi:10.1016/j.foodhyd.2007.04.009

Ringers, H. J., & Segers, J. C. (1977). *Degumming process for triglyceride oils* (U.S. Patent No. 4,049,686). Retrieved from https://patentimages.storage.googleapis.com/pdfs/US4049686.pdf

Rossi, M., Alamprese, C., & Ratti, S. (2007). Tocopherols and tocotrienols as free radical-scavengers in refined vegetable oil and their stability during deep-fat frying. *Food Chemistry, 102*, 812-817. doi:10.1016/j.foodchem.2006.06.016

Smiles, A., Kakud, Y., & MacDonald, B. E. (1988). Effect of degumming reagents on the recovery and nature of lecithins from crude carona, soybean and sunflower oils. *Journal of the America Oil Chemists' Society, 65*(7), 1151-1155.

Soe, J. B., & Turner, M. (2012). *Enzymatic oil-degumming method*. (US Patent 8192782 B2). Retrieved from https://www.google.ch/patents/US8192782

Standards Malasia. (2007). *MS816: Palm olein specification*. Retrieved from https://archive.org/details/ms.816.2007

Szydlowska-Czerniak, A. (2007). MIR spectroscopy and partial least-squares regression for determination of phospholipids in rapeseed oils at various stages of technological process. *Food Chemistry, 105*, 1179-1187. doi:10.1016/j.foodchem.2007.02.038