Jurnal
Teknologi

Full Paper

PHYSICO-CHEMICAL PROPERTIES OF RECYCLED REFINED, BLEACHED AND DEODORIZED (RBDPO) PALM OLEIN: WHICH CYCLE SHOULD THE OLEIN CONSIDERED SPOILAGE?

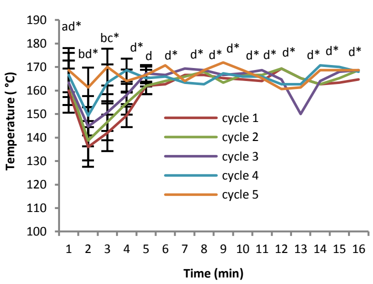
Ili Afiqa Ab Kadir, Lailatul Syema Jurid, Saiful Irwan Zubairi*

School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia

Article history
Received
24 October 2016
Received in revised form
15 February 2017
Accepted
15 March 2017

*Corresponding author:
saiful-z@ukm.edu.my

Graphical abstract



Abstract

Palm olein is widely used for domestic and commercial frying but its usage beyond recommended cycle might lead to spoilage. Therefore, this study focuses on the comprehensive analysis of chemical and physical properties of recycled palm olein. It was prepared by frying potato strips up to 5 cycles with potato (g)-to-oil (ml) ratio of 3/20 prior to physico-chemical analysis. The temperature profile of RBD palm olein throughout frying also been investigated. It was done by taking the palm olein temperature during the frying of potato strips within 15 minutes for each cycle. There were physico-chemical analyses included colour measurement, viscosity, iodine value, peroxide value, moisture content, contact angle and density. However, according to the present result, peroxide value and contact angle was quite unsuitable or weak for the oil spoilage analysis for the first 5 cycles. Whereas moisture content, colour measurement, density, viscosity and iodine value were insignificant (p>0.05) for all cycles. Thus, those results could not be considered as definite indicators for spoilage assessment. This might be due to the starch composition within the potato strips that shows no changes despite 5 frying cycles. For that reason, further analysis (greater than 5 cycles) is needed to confirm at which oil cycle of that oil should become spoiled.

Keywords: Physico-chemical, peroxide value, recycled palm oil, oil spoilage, contact angle

Abstrak

Minyak kelapa sawit digunakan secara meluas bagi tujuan penggorengan domestik dan komersial. Tetapi jika penggunaannya melampaui jumlah yang disarankan, ia membawa kepada kerosakan minyak tersebut. Oleh itu, kajian ini memfokus kepada analisis komprehensif tentang sifat fiziko-kimia minyak kelapa sawit terpakai. Minyak kelapa sawit terpakai disediakan melalui penggorengan kentang untuk 5 kitar dengan nisbah 3/20 kentang (g) kepada minyak (L). Profil suhu minyak kelapa sawit terpakai juga dikaji. Ia dijalankan dengan mengambill bacaan suhu minyak sawit olein ketika penggorengan kentang jejari pada setiap minit untuk setiap kitar penggorengan. Terdapat beberapa analisis fiziko-kimia dijalankan ke atas minyak kelapa sawit terpakai. Analisis tersebut merangkumi ukuran warna, kelikatan, nilai iodin, nilai peroksida, kandungan kelembapan dan ketumpatan. Walau bagaimanapun, berdasarkan keputusan terkini, nilai peroksida dan sudut sentuh merupakan penunjuk aras kerosakan minyak yang kurang stabil atau lemah. Sementara itu, kandungan kelembapan, ukuran warna, ketumpatan, kelikatan dan nilai iodin menunjukkan keputusan tidak signifikan (p>0.05) bagi kesemua kitar penggorengan. Oleh yang demikian, kesemua analisis tersebut tidak boleh dijadikan sebagai penunjuk aras utama bagi kerosakan minyak kelapa sawit terpakai. Hal ini mungkin disebabkan oleh komposisi kanji di dalam kentang jejari yang tidak menunjukkan sebarang perubahan signifikan selepas 5 kitar penggorengan. Oleh yang demikian, analisis lanjutan (lebih daripada 5 kitar penggorengan) perlu dijalankan bagi menentukan pada kitar yang manakah minyak akan mulai mengalami kerosakan.

Kata kunci: Fiziko-kimia, nilai peroksida, minyak masak kitar semula, kerosakan minyak, sudut sentuh

1.0 INTRODUCTION

Palm oil is widely used in many industrial and culinary processes. However, it is well known that oils degrade with heating. The degradation of oil level depends on the frying temperature and frying time. As a consequence of its thermal degradation during frying, a few compounds are present in the spoiled palm oil. This is a matter of interest since some of the compounds might be toxic and harmful for consumption and health [1].

As the frying medium, palm oil is exposed to simultaneous conditions from the food, high temperature and also atmospheric oxygen [2]. The formation of oxidised monomers, dimers and oligomers of triacyglycerol were the effects of oxidation due to the presence of atmospheric oxygen. Not just that, the water evaporation during frying produces a steam blanket over frying oil. It has been found that if the steam blanketing limits the oxygen supply during frying, the main reactions lead to polymerisation rather than oxidation [3]. Moreover, it is generally accepted that moisture interacts with oil, resulting in hydrolytic reactions, which will result in free fatty acids, diacylglycerol, monoacylglycerol and glycerol yield. Although some experiments have reported the increase in hydrolysis products during frying, others have not detected any of hydrolysis products increase [4].

All the chemical reactions lead to a lengthy list of primary until tertiary products and most of the products are volatile and automatically eliminated to the air during frying. The non-volatile compounds, for instance dimers of triacylglycerol, accumulate in the frying oil and the accumulation has an effect on the total oil/fat chemical changes [3].

Whether it is oxidation or polymerisation, both need to be avoided. Several types of diseases may be related to the exposure of humans to food- or air-borne breakdown products of heated oils. It includes atherosclerosis, the forerunner to cardiovascular disease; inflammatory joint disease, including rheumatoid arthritis; pathogenic conditions of the digestive tract; mutagenicity and genotoxicity, properties that often signal carcinogenesis; and teratogenicity, the property of chemicals that leads to the development of birth defects.

Similarly, polymerisation of cooking oil gives negative impacts to the consumer. From a nutritional point of view, the polymers of high molecular weight are indigestible. Consequently, there is little importance with regard to nutrition and health, but the shortest compounds, monomers and dimers, are indeed absorbed by the intestinal walls, having an effect on the consumer's health. Many of these substances are recognised as toxic or potentially carcinogenic, for instance, the benzopyrene produced by cholesterol cyclization.

In order to analyse the fried fats and oils and describe chemical changes during frying, several physical and chemical methods were carried out. Each method provides different information on the changes. Among them, peroxide value is most frequent used as quality parameter as it shows the degree of oxidation in the substances and measures the amount of total peroxides as a primary oxidation product [5]. Besides, iodine value is also an indicator of oil quality. It measures the degree of unsaturation of fatty acids. The examples of unsaturated fatty acids are mono-unsaturated fatty acid (MUFA) and poly-unsaturated fatty acids (PUFA). This is due to the fact that the degree of saturation and concentration of PUFA affects various chemical reactions in the oil/fat differently [6].

Despite these two chemical methods, there are physical methods such as density, moisture content, viscosity and colour measurement. The moisture content in food has an effect on frying oil as Fedeli [7] and Dana [8] have found separately on the effect of water in the form of steam bubbles and on the effect of starch and protein plus the different interactions that occurred to frying oil or fat. Other physical method that is regularly used is colour measurement due to its nature of quick check on degradation and the suitability and stability for a particular purpose. Manually operated visual instruments were used back then [9]. The product to be measured is compared to either coloured glass [10] or reference solutions [11]. Knowing that visual methods are not adequate for objective assessment, automated colorimetres are in need and being widely used now [12].

Despite the vast literature review on frying and the analytical methods used to analyse frying oil quality, a serious gap appears in the literature. To the best of our knowledge, no comparative study exists correlating physical and chemical properties of recycled palm oil. This gap is not due to the lack of interest of the subject, but rather mainly due to experimental difficulties. For that reason, this study focuses on the comprehensive analysis of chemical and physical properties of recycled palm oil (less than 5 cycles) and to identify at which cycle that the frying oil started to become spoilage.

2.0 METHODOLOGY

The overview of the palm oil spoilage studies is shown in Figure 1.

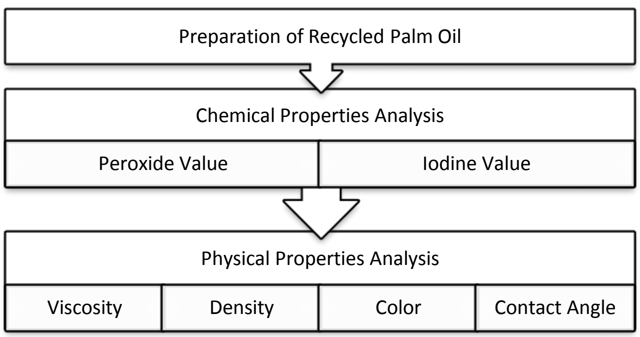


Figure 1 Flow chart of all analysis done throughout the studies

2.1 Preparation of Recycled Palm Oil

Refined palm oil (Buruh, Lam Soon Edible Oils Sdn. Bhd., Malaysia) was used in this study. The potatoes were bought from the same local market (CS Market, Malaysia). The size of the potato strips was standardised for each frying process. Repeated frying experiments are conducted to produce recycled palm oil.

Frying was conducted in a commercial fryer (FABER, FDF 1035ss, Malaysia) with a maximum oil capacity of 3.5 L and nominal power of 2000W. The frying series started with 2000 ml of fresh oil in the fryer with frying temperature of 180 ± 5 °C. The volume of oil (ml_{oil}), decreased after every cycle. It is due to sampling of oil and also oil absorption from the potatoes. The oil was not replenished between frying batches. Thus, in order to keep the frying load constant throughout the 4 batches (frying load: 3/20 $g_{potatoes}/ml_{oil}$), the mass of the potatoes in the fryer was reduced accordingly. Each frying batch lasted for 75 minutes and the duration of each cycle was approximately 15 minutes.

In order to obtain temperature profile data, the refined palm oil temperature reading was taken for each minute during the frying. Thermostat was used to avoid the temperature from fluctuate.

2.2 Chemical Properties Analysis

2.2.1 Determination of Iodine Value

Iodine values of the recycled palm oil were determined according to American Oil Chemist's Society (AOCS) Official Methods Cd 1-25. First, 0.5 g of the oil sample was transferred into a 250 ml flask before adding 15 ml tetrachloromethane and exactly 25 ml of Wijs solution. The flask was swirled and kept in the dark for 1 hour. After 1 hour, 20 ml of potassium iodide (KI) and 150 ml distilled water was added to the solution. Then, the mixed solution was titrated with 0.1M sodium thiosulphate ($Na_2S_2O_3$) solution until it turned into yellow due to the iodine compound almost disappeared. Then, 1-2 ml starch indicator solution was added and titrated continually until its blue color disappeared after very vigorous shaking. The iodine value was expressed in the mass of iodine in grams that is consumed by 100 grams of a chemical substance, calculated as:

$$\text{Iodine value (g/100 g)} = 12.69N\,(V_2 - V_1)/W$$

N = Normality of sodium thiosulphate used
V_2 = blank $Na_2S_2O_3$
V_1 = test volume $Na_2S_2O_3$
W = weight (g) of sample

2.2.2 Determination of Peroxide Values

Peroxide values of the recycled palm oil was determined according to American Oil Chemist's Society (AOCS) Official Methods Cd 8-53. In short, 5 g of oil sample was transferred into a 250 ml flask prior to the addition of 30 ml of acetic acid-chloroform (3:2). The flask was swirled and next 0.5 ml of saturated potassium iodide was added. Following that, the solution was swirled again for 1 minute and 30 ml of distilled water and 0.5 ml of starch solution (10%) were added. The solution was titrated against 0.01N sodium thiosulphate solution. The peroxide value was expressed in milliequivalents of peroxide per kg of the sample calculated as:

$$\text{Peroxide value (meq/kg)} = [(V_a - V_b)N \times 1000]/W$$

Where:

V_a = volume of sodium thiosulphate solution (ml)
V_b = volume of sodium thiosulphate solution (ml) used for the blank
N = normality of sodium thiosulphate
W = weight of the test portion (g)

2.3 Physical Properties Analysis

2.3.1 Viscosity Measurement

A concentric cylinder viscometer (LVDV-II+, Brookfield, Brookfield Engineering Laboratories, Inc., USA) was used in this experiment. Spindle 4 was used under temperature of 25 °C with the constant shear rate 100 s^{-1}.

2.3.2 Density Measurement

Oil or fat density was determined manually by using measuring cylinder (Pyrex, Malaysia) and digital weighing scale (ALC 1100-2, India).

2.3.3 Moisture Content Measurement

The moisture content of recycled palm oil was determined by using Pocket Moisture Refractometer (ATA0090, ATAGO, Japan). The recycled palm oil was applied on the prism and the pocket refractometer detected the sample and the moisture content was shown on the LCD.

2.3.4 Color Measurement

A portable, battery operated colorimeter (CR410, Konica Minolta Sensoring America Inc., USA) was used to test the colour of 20 samples of recycled palm oil (according to the operator's instruction manual). Triplicate measurements were carried out for accuracy and repeatability purposes.

2.3.5 Contact Angle

Static contact angle was used to measure contact angle of oil on the glass slide using Automated Contact Angle Goniometer Model 100 (Ramé-Hart Instruments) as shown in Figure 2. Glass slide (*soda lime*, 76 mm x 26 mm x 1 mm) used is from Quasi-S Technology Sdn. Bhd. Soda lime glass slide is made of Na_2O, Al_2O_2, MgO and CaO give its hydrophilic properties. Oil sample is preheat up to 80 °C for 45 minutes in water bath to melt any solid or crystal formed [26]. Oil sample was then left to be cooled until it reached 40 °C before analysed. Soda lime glass slide was cleaned with ethanol and 20 µl of oil was dropped on its surface using syringe.

Figure 2 Automated Contact Angle Goniometer Source: Nuclear Department, UKM 2016

2.4 Statistical Analysis

All data was analysed using the Statistical Package for the Social Sciences (SPSS) version 21.0. The one-way ANOVA and Tukey's correlation were used. For the determination of significant differences between the samples, the probability of significant levels determined in 95% ($p<0.05$). Data was presented as means ± standard deviation (SD) of mean values. A $p<0.05$ was considered significant.

3.0 RESULTS AND DISCUSSION

3.1 Temperature Profile of Recycled Palm Oil through Frying Process

Figure 3 shows the temperature profile of recycled palm oil over time. Generally, after a minute of frying, the palm oil temperature dropped on each cycle ($p<0.05$).

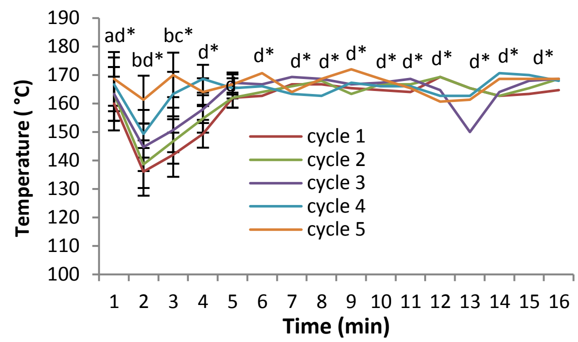


Figure 3 Temperature profile of recycled palm oil of different frying cycles. Values were presented as mean ± SD (n = 3) and the data interpreted using ANOVA analysis. *Different letters indicate significant differences ($p<0.05$)

The temperature of oil should be remained stable due to the presence of temperature controller of the fryer. This might be due to the loading of potato strips into the fryer since heat and mass transfer occurred between oil and food. This was in line with Chen and Farid's [13] findings as they were carried out a research regarding heat and mass transfer using the heat conduction equation. The model developed assumes the presence of two regions, the fried and the unfried regions. The generated heat from the oil to the surface of the food was transferred by conduction through the fried region to an evaporating interface. Most of the transferred heat is utilised to vaporise the water at the interface, while the remaining smaller amount is used for sensible heating. The generated water vapour at the interface was assumed to flow in the fried region with minimum resistance, exchanging heat with the solid. The model was tested against some experimental results available for frying of thick and thin potato chips. The agreement between the predicted and measured temperature distribution was reasonable except at the end of the frying period at which the bounded water may vaporise with a different mechanism and oil may penetrate deep into the potato chips.

Based on Figure 3, the fluctuation trend of recycled temperature in this study exhibited a slight difference between two group which are group 1 and group 2 ($p<0.05$). Group 1 was cycle 1, 2 and 3 and group 2 was cycle 4 and 5. For group 1, the temperature of oil dropped until minute 3 and it rose back at minute 4 to minute 7. Then, its temperature went up and down till minute 15.

On the contrary, for group 2, the oil temperature dropped only at minute 1 and rose back at minute 2 until minute 3. Then, its temperature went up and down till minute 15. However, the fluctuation were considered insignificant (p>0.05).

3.2 Physical Properties Analysis

3.2.1 Density of Recycled Palm Oil

Density is an important physical characteristic of any substance, and is a measure of the mass per unit of volume of that substance. It is an accepted fact that vegetable oil density decreases linearly with increasing temperature. Based on Figure 4, the density of palm oil were quite constant at 0.15 g/cm^3 except for cycle 2 with 0.17 g/cm^3.

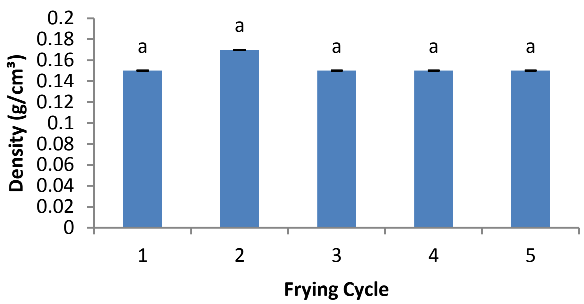


Figure 4 Recycled palm oil density profile of different frying cycles. Values were presented as mean ± SD (n = 3). Different letters indicate significant difference (p<0.05)

Kalogianni *et al.* [14] stated that frying batch number is a significant variable (a = 0.05) affecting the density of oil. Tuckey's Test with confidence intervals (CI) of 95% was used to justify the result and it showed that changes in density become significant only from the 20th frying batch and on. Knowing this experiment only run frying up to 5 frying cycles, the result of density as shown in Figure 4 was expected.

3.2.2 Moisture Content in Recycled Palm Oil

As shown in Figure 5, the moisture content of recycled palm oil showed insignificant decreases with frying cycle. On the other hand, Krokida *et al.* [15] stated that moisture content of potato strips decreases significantly during frying due to water loss to the frying oil. The oil temperature decreased with the increase of fried potatoes moisture content. Thus, it also means that it increases with the increase of frying oil moisture content.

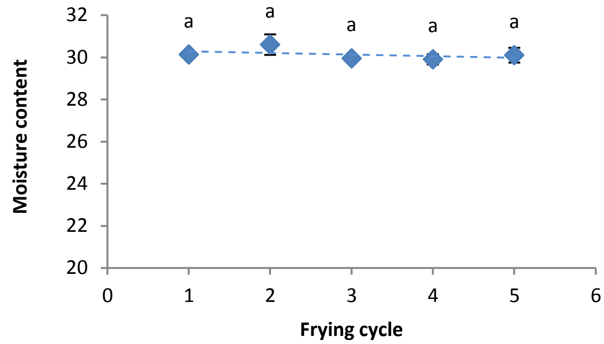


Figure 5 Moisture content profile of different frying cycles. Values were presented as mean ± SD (n = 3). Different letters indicate significant difference (p<0.05)

However, the decreasing trend of moisture content of recycled palm oil over frying cycle was insignificant in this study. This situation occurred might be due to formation of hydrolysis products which are volatile while frying process [4]. But the remaining non-volatile compounds among the hydrolysis products might have been accumulated in palm oil and thus affected the total oil/fat chemical changes [3].

3.2.3 Color Measurement of Recycled Palm Oil

Colour measurement using the pocket refractometer is simpler compared to visual comparative techniques and it involves three short steps: (i) dotted 0.3 mL palm oil sample on the prism, (ii) pressing start button to initiate the colour measurement, and (iii) taking the results of moisture content value displayed by the LCD. A large number of colour determinations can be carried out in a short time, as less than 5 seconds is required per analysis.

Theoretically, frying oil became darker in colour after frying process. As shown in Figure 6(a), the trend line illustrates that with increasing frying times, recycled palm oil lightness decreases. It also means that its colour has been darker. Meanwhile in Figure 6(b), the tendency to green colour (b*) rate increase indicating that recycled palm oil show tends to become green in colour. Whereas, in Figure 6(c), tendency to red colour (a*) rate decreased showing the oil has low tendency towards the color red. All of these observations show that with increasing frying times, recycled palm oil colour became darker due to chemical reaction that occur during frying. The main factors affecting the changes in colour are oil type, storage and thermal changes, interfacial tension between the oil and the food, moisture content, length and temperature of frying and pre-frying treatments.

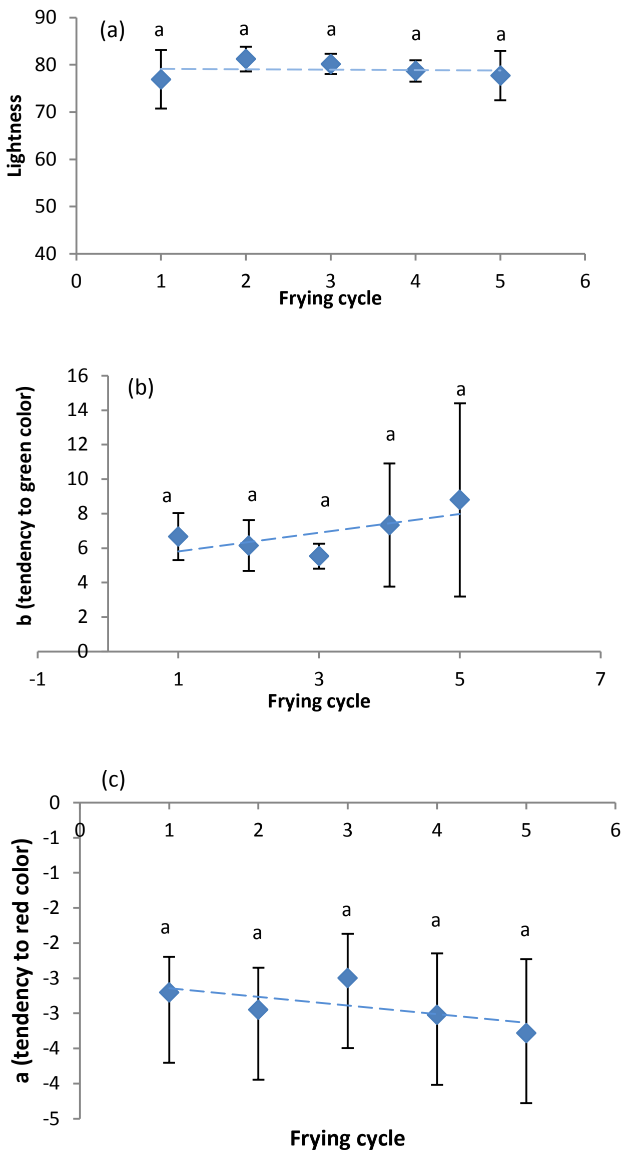


Figure 6(a) Lightness of recycled palm oil throughout frying cycle. (b) Tendency of recycled palm oil to green color of different frying cycles. (c) Tendency of recycled palm oil turn to red color of different frying cycles. Values were presented as mean ± SD (*n* = 3). Different letters indicate significant difference (*p*<0.05)

A decrease in lightness (L*) with frying cycle may be due to Maillard browning reaction and caramelisation at the high frying temperature as any effect of sugar from the potato itself. Maillard reaction depends on its chemical environment such as water activity, pH, chemical composition of the food and the reaction temperature [23]. Whereas the intensity of browning is primarily correlated with the losses of lysine, histidine, and methionine.

The polymer formation of unsaturated carbonyl compounds and non-polar compounds of foodstuff solubilized in the oil was reported as factors of oil color changes after frying [24]. The aldehydes, epoxides, hydroxyketones, and dicarboxylic compounds formed from the lipid oxidation react with amines, amino acids, and proteins in fried foods [25].

The reaction between epoxyalkenals and proteins produces polypyrrolic polymers as well as volatile heterocyclic compounds [26]. Carbonyl compounds formed in lipid oxidation would react with amino acids, especially asparagines, and produce acrylamide and decrease the nutritional value and safety of foods.

3.2.4 Contact Angle

Theoretically, the higher the frying cycles, the greater the fluid becomes viscous and thus lower the wettability of the liquid on the solid surface. In other words, the lower the wettability, the higher the contact angle of oil on solid surface. Based on Figure 7, contact angle of oil decrease significantly (*p*<0.05) between the first cycle and fifth cycles. The decrement of contact angle were observed between the first cycle and the fifth cycle ranging from 32.53 ± 0.5° to 18.06 ± 0.15° (*p*<0.05).

However, the result from this recent study was contradicted with the theory as the higher the number of frying cycle, the lower the oil contact angle observed. The main reason was probably due to the contact angle decreased as the moisture content in the oil at the fifth cycle was higher than in the first cycle (*p*<0.05). According to Rossi *et al.* [26], the longer the frying time, some products of oxidation and hydrolysis are formed, causing a decrease in surface tension between oil and food and at the same time reducing the contact angle. Thus, after the fifth frying cycle, there was a significant reduction in its contact angle. On the contrary, moisture content of all samples were considered the same until cycle 5. Measurement errors such as improper heating (to dissolve solidify oil) and oil temperature fluctuation during contact angle analysis would have deviated the contact angle profiles contradictorily.

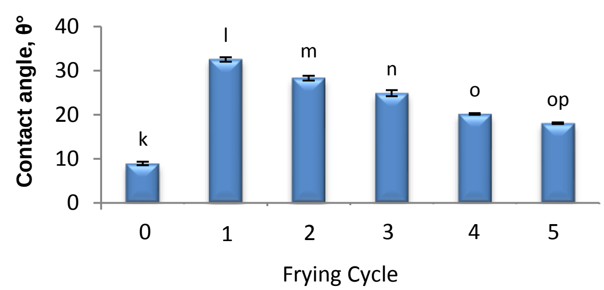


Figure 7 Contact angle profile of different frying cycles. Value stated in mean ± SD (*n* = 3). k-pMean with different alphabet indicate significant different of frying cycles (*p*<0.05)

3.2.5 Viscosity of Recycled Palm Oil

Viscosity is a measure of the resistance offered by a fluid to flow. According to Krisnangkura *et al.* [18]

viscosity may be considered the integral of the interaction forces of molecules. When the heat is applied to fluids, molecules can then slide over each other more easily making the liquid to become less viscous.

As shown in Figure 8, the viscosity of recycled palm oil increases insignificantly with frying time. There were few studies found that edible vegetable oils viscosity decreases with temperature increase. This was due to a higher thermal movement among molecules, reducing intermolecular forces, making flow among them easier and reducing viscosity. This behaviour was also verified by researches [19], who observed that flow behaviour is changed by sample temperature.

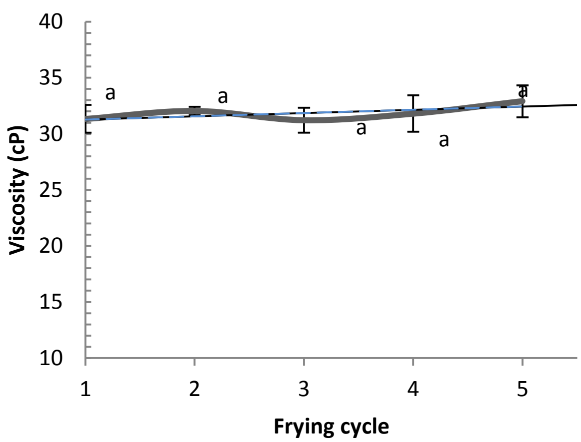


Figure 8 Recycled palm oil viscosity of different frying cycles. Values were presented as mean ± SD (n = 3). Different letters indicate significant difference (p<0.05)

According to the results in Figure 8, it can be observed that recycled palm oil viscosity increases with frying time. This is similar to Moretto & Fett's [20] findings that may be due to oxidation and polymerisation reactions. Not just that, Santos *et al.* [21] discovered in the present case that oxidation (accelerated by frying time and temperature) is the main agent responsible for modification in physical-chemical and organoleptic characteristics of the oils. During degradation, oil saturation increases, as well as formation hydroperoxide and other degradation products, leading to non-volatile compounds, as cyclic monomers, dimers, trimers and high molecular weight compounds [22].

Generally, oxidation reactions lead to the formation of carbonyl and/or hydroxyl groups bonded to carbon chain. Oxygen may lead to the formation of hydrogen bonds that increase intermolecular forces, making flux among molecules more difficult and increasing viscosity. In relation to polymerisation, the increase in chain size leads to the increase in the electron number in the molecule, increasing London forces and, one more time, intermolecular forces. Besides, longer chains are more difficult to move, leading to a higher viscosity.

3.3 Chemical Properties Analysis

3.3.1 Peroxide Value of Recycled Palm Oil

Peroxide value test is necessary to quantitatively determine if the oil was oxidised and the degree of the oxidation. Its value shall increase throughout frying process because frying supply atmospheric oxygen to the oil and leads to oxidation. Changes in the PV of the recycled palm oil is shown in Figure 9. The palm oil showed decreasing trend from cycle 1 until cycle 5. Such a result of this study apparently complied with the result of the study conducted by Fritsch which reported that PV is not suitable analysis for the used frying oils. Plus, Augustin and Berry [16] also reported that PV is a problematical indicator for the oxidative deterioration of fats and oils during deep-frying since peroxides are destroyed by high temperature and new peroxides formed during cooling.

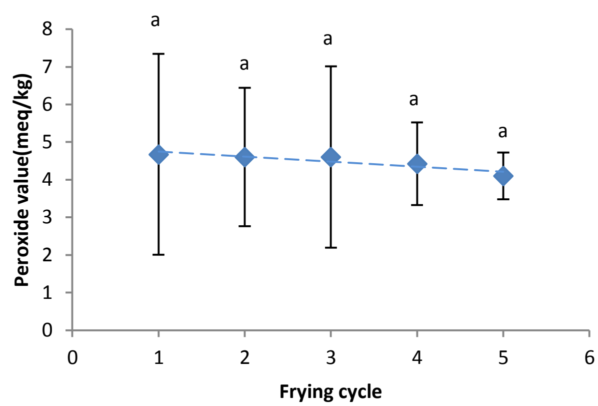


Figure 9 Recycled palm oil peroxide values of different frying cycles. Values were presented as mean ± SD (n = 3). Different letters indicate significant difference (p<0.05)

Likewise, the recent study stated that none of the oil samples exceed the limit of 10 meq O_2/kg oil for edible oils and the limits of 5 and 7 meq O_2/kg oil in accordance with AOCS and ISIRI, for used frying oils, respectively. Thereby, PV may not indicate the real extent of oil spoilage and deterioration and it is not recommended for measuring oil spoilage purpose.

3.3.2 Iodine Value of Recycled Palm Oil

Iodine value measures the degree of unsaturation of fatty acids. The higher the iodine value, the more unsaturated the fat is. In the same way, the trend of IV in Figure 10 also increases along the frying cycles.

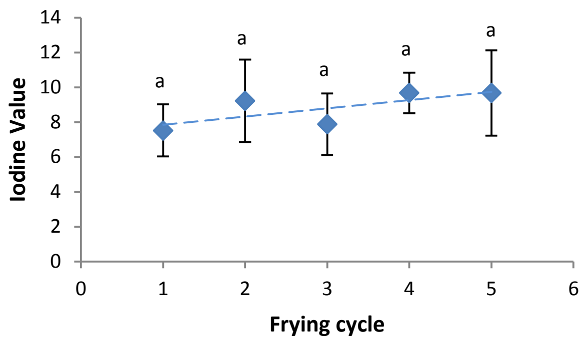


Figure 10 Iodine value profile of different frying cycles. Values were presented as mean ± SD (n = 3). Different letters indicate significant difference (p<0.05)

It is now well known that the fatty acid composition depends on the origin of plants. Thus, the differences in saturated fatty acid (SFA), mono-unsaturated fatty acid (MUFA), and polyunsaturated fatty acid (PUFA) contents found in the previous study can be easily explained [17]. For instance, RBDPO, refined, bleached, and deodorized palm super olein (RBDPOSO), red palm olein (RPO) and RBDPOS are oil samples obtained from palm pulp where RBDPOSO and RBDPOS are two main fractions of RBDPO. In these oil samples, the SFA accounted for more than 43%, while the MUFA, mainly oleic (C18:1) acid, made up about 20–44% of the total FA. The PUFA content ranged from 4–12%, which also indicates the amount of linoleic (C18:2) acid. These oils were distinguished from other oils by high levels (38.1-68.3%) of palmitic (C16:0) acid. The predominance of this fatty acids was the main reason for the low IV in palm based oil products. The fractionation of RBDPO into olein and stearin fractions has a significant influence on FA composition [17].

4.0 CONCLUSION

This work provides experimental evidence that the physico-chemical analysis is able to detect chemical changes or spoilage of recycled palm oil. However, according to the present result, peroxide value and contact angle were considered quite unsuitable/weak for the oil spoilage analysis for the first 5 cycles. Whereas moisture content, colour measurement, density, viscosity and iodine value were not significant across all cycles, thus could not be a distinguishing indicator for spoilage assessment. It might be due to the starch composition within potato strips that shows no changes despite of 5 frying cycles. For that reason, further analysis (greater than 5 cycles: up to 15 cycles) is needed to confirm at which oil cycles should oil become spoiled. Plus, another type of food with different compositions such as fatty acid might give significant results for the physico-chemical analysis.

Acknowledgement

The authors would like to thank the Ministry of Science, Technology and Innovation (MOSTI) and Ministry of Higher Education (MOHE) Malaysia for providing financial support to this project (06-01-02-SF1271, FRGS/2/2013/TK04/UKM/03/1 and GGPM-2013-078).

References

[1] Innawong, B., P. Mallikarjunan, and J. E. Mersi. 2004. The Determination of Frying Oil Quality Using a Chemosensory System. *Le-bensm Wiss u Technology*. 37: 35-414.

[2] Gertz, C., S. Klostermann, and S. P. Kochnar. 2000. Effect of Frying-Cooking on Nutritional and Bioactive Compounds of Innovative Ovo-Vegetarian Diets. *European Journal of Lipid Science and Technology*. 102(-): 543-551.

[3] Gutierrez, R., F. Gonzalez-Quijano, and M. C. Dobarganes. 1988. Analytical Procedures for the Evaluation of Used Frying Fats. In: Varela, G., Bender, A. E., Morton, I. D. (eds). Frying Of Food Principle Changes, New Approaches. Ellis Horwood Ltd, Chichester. 141-154 .

[4] Dana, D., M. M. Blumenthal, and I. S. Sagus. 2003. The Protective Role of Water Injection on Oil Quality in Deep Frying Conditions. *European Journal of Lipid Science and Technology*. 217(-): 104-109.

[5] Berlin, H. D., W. Grosch, and P. Schieberle. 2004. *Food Chemistry*. 3rd edition. Berlin.

[6] Houhoula, D. P., V. Oreopoulou, and C. Tzia. 2003. The Effect of Process Time and Temperature on the Accumulation of Polar Compounds in Cottonseed Oil During Deep-fat Frying. *Journal of Science Food Agriculture*. 83(-): 314-319.

[7] Fedeli, E. 1988. The Behavior of Olive Oil During Cooking and Frying. In: Varela, G., Bender, A. E., Morton, I. D. (eds). Frying of Food Principle Changes, New Approaches. Ellis Horwood Ltd, Chichester. 52-81.

[8] Morrison, W. R., and L. M. Smith. 1964. Preparation of Fatty Acids Methyl Esters and Diethylacetals From Lipids with Boron Fluoride-methanol. *Journal of Lipid Research*. 5(-): 600-608.

[9] Fawcett, G. S. 1994. Sixty Years of Calorimetry. *Proceeding of Physical Society*. 56(-): 8-21.

[10] 1997. Animal and Vegetable Fats and Oils-determination of Color-tintometer Method. ISO 15303;

[11] AOCS. 1997. *Wesson Method Using Color Glasses Calibrated in Accordance with the AOCS-Tintometer Color Scale, Official Methods and Recommended Practices of the AOCS*. 5th edition. AOCS Press. Champaign. CC 13b-45.

[12] AOCS. Color-Gardner 1963 (glass standards). 1997. Official Methods and Recommended Practices of the AOCS. 5th edition. AOCS Press. Champaign. 1997. Td 1a-64.

[13] Ghani, A. G., M. M. Farid, and X. D. Chen. 1998. Presented at 26th Austrian Chemical Engineering Conference (ACEC).

[14] Kalogianni, E. P., T. D. Karapantsios, and R. Miller. 2010. Effect of Potato Presence on the Degradation of Extra Virgin Olive Oil During Frying. *International Journal of Food Science and Technology*. 45(-): 765–775.

[15] Krokida, M. K., V. Orepoulou, and Z. B. Maroulis. 2000. Water Loss and Oil Uptake as a Function of Frying Time. *Journal of Food Engineering*. 44(-): 39-46.

[16] Agustin, M. A., and S. K. Berry. 1983. Efficacy Of The Antioxidants. *Journal of the American Oil Chemists' Society*. 60(8): 1520-1523.

[17] Tan, C. P., and Y. B. Che Man. 2000. Differential Scanning Colorimetric Analysis of Edible Oils: Comparison of Thermal Properties and Chemical Composition. *Journal of American Oil Chemist's Society*. 77(-): 2.

[18] Krisnangkura, K., T. Yimsuwan, and Parintra, R. 2006. An Empirical Approach In Predicting Biodiesel Viscosity At Various Temperatures. *Fuel*. 85(-): 107-113.

[19] Kahn, R., D. Stehli, L. Wei, S. Steinberg, and N. Yamashita. 1990. Activity and Mobility of Water in Sweetened Concentrated Dislodged Soy Beverages and Their Rheological Properties. *Journal of Food Science.* 55 (2): 537-542.

[20] Moretto, E., and R. Fett. 1998. *Technology of Vegetable Oils in Industry*. Second Edition. Chemistry and Technology of Vegetable Oils.

[21] Santos, I. M. G., and A G. Souza. 2005. Effect of Heating and Cooling on Rheological Parameters of Edible Vegetable Oils. *Journal of Food engineering.* 67(-): 401-406.

[22] Kowalski, B., K. Ratusz, A. Miciula, and K. Krygier. 1997. Monitoring of Rapeseed Oil Autoxidation with a Pressure Differential Scanning Colorimeter. *Thermochimica Acta.* 307(-): 117-121.

[23] Carabasa, M., and A. Ibarz. 2000. Kinetics Of Colour Development In Aqueous Glucose Systems At High Temperatures. *Journal of Food Engineering.* 44: 81-189.

[24] Yaghmur, A., A. Aserin, Y. Mizrahi, A. Nerd, and N. Garti. 2001. Evaluation of Argan Oil for Deep-Fat Frying. *Lebensm-Wiss u-Technol.* 34: 124-130.

[25] Pokorny, J. 1981. Browning from Lipid-Protein Interaction. *Prog Food Nutr Sci*. 5: 421-8.

[26] Rossi, M., Alamprese, C., Ratti, S. and Riva, M. 2009. Suitability of Contact Angle Measurement as an Index of Overall Oil Degradation and Oil Uptake During Frying. *Food Chemistry*. 112(2): 448-453.