EVALUATION AND DEVELOPMENT OF QUALITY INDICES FOR ADULTERATION IN PALM OIL INDUSTRY BY USED AND RECYCLED OILS

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FSTM 2019 22

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Tan Chin Ping, PhD
Faculty : Food Science and Technology

Currently, recycled oil has emerged as a prominent food safety issue and poses a major threat to the public health. Various studies have been conducted to detect the adulteration of used and recycled palm olein in refined, bleached, and deodorized palm olein (RBDPO). The presence of polymerized triacylglycerols (PTGs), monomeric oxidized triacylglycerols (oxTAGs), or caprylic acid (C8:0) has been proposed as a potential indicator to track the adulteration. Therefore, this study investigates the presence of these compounds in commercial cooking oils, their formation during various heating and deep-frying studies, and their presence in recycled oil samples. This study can be used to justify the suitability of these compounds for use as the quality indicators to trace the adulteration of used or recycled oil.

In the first part of this study, a total of 23 commercial cooking oil samples were purchased from a market in Malaysia and were categorized into three main groups, namely, pure palm olein, blended palm olein, and packet oil. The total polar compounds (TPCs) for all fresh oil samples were within the safety limit for human consumption ($<$ 25% polar compounds) set in many European countries. No triacylglycerol (TAG) oligomers, epoxy-, keto-, or hydroxy acids were detected in any of the fresh oil samples.

In the second part of this study, a controlled heating study was carried out, RBDPO was heated continuously for 24 h at 160 °C, 170 °C, and 180 °C, with the oil sampled at 4-hour intervals. The oxTAG, TPC, and PTG concentrations in RBDPO increased significantly ($p<0.05$) with the temperature and heating time. At the end of the heating study, more epoxy acids were formed compared to keto and hydroxy acids. However, the TPC exceeded the limit of rejection for human consumption ($>$25% polar compounds). Moreover, caprylic acid, which was not present in fresh oil, was formed in significant amounts after the controlled heating study.

In the third part of this work, two different types of food products, namely, sliced potato (SP) and chicken breast meat (CBM) were fried in a total duration of 200 min/day for seven consecutive days using RBDPO at 180 °C without any oil replenishment. The amounts of TPC, PTG, and caprylic acid that formed were significantly ($p < 0.05$) higher in the RBDPO used to fry SP compared to that used for CBM. The TPC in the RBDPO used to fry SP exceeded the limit of rejection for human consumption (> 25% polar compounds) on the seventh day of frying. In addition, the amounts of epoxy, keto, and hydroxy acids that formed were significantly ($p < 0.05$) higher in the RBDPO used to fry CBM compared to that used for SP.

Following this, oil samples that underwent controlled heating and deep-frying studies were refined using the common oil refining procedure to simulate the production of recycled oil. PTG, TAG oligomers and dimers showed a significant increase ($p < 0.05$) after the refining process. The oxTAG, free fatty acid (FFA), peroxide value (PV), and *p*-anisidine value (AV) dropped significantly ($p < 0.05$) in the recycled RBDPO after the refining process. For the last part of the study, FT-NIR spectroscopy coupled with chemometrics was used to rapidly quantify the amount of thermo-oxidative products such as PTG, oxTAG, and TPC formed in used frying oil. Three separate partial least squares regression (PLS) models were built with high calibration accuracy.

In conclusion, the few proposed potential quality indicators, namely PTG, oxTAG, and caprylic acid, were all detected in recycled oil. These findings justified the suitability of these parameters to be used in the quality indices to trace the adulteration of cooking oil as these compounds were not detected in the fresh oil. It is our hope that the findings of this study will be able to control the adulteration of used and recycled palm olein in RBDPO for the protection of the health and safety of consumers.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN DAN PEMBANGUNAN INDEKS KUALITI UNTUK MENGESAN PENYALAHGUNAAN MINYAK TERPAKAI DAN KITAR SEMULA DALAM INDUSTRI MINYAK KELAPA SAWIT

Oleh

KHOR YIH PHING

Mei 2019

Pengerusi : Profesor Tan Chin Ping, PhD
Fakulti : Sains dan Teknologi Makanan

Pada masa kini, isu keselamatan minyak masak kitar semula telah menjadi salah satu permasalahan yang dapat meningkatkan risiko negatif kepada kesihatan pengguna. Pelbagai kajian telah dilakukan untuk mengesan penyalahgunaan minyak terpakai dan kitar semula di dalam minyak kelapa sawit tertapis, terluntur, dan ternyahbau (RBDPO). Kehadiran polimer triasilgliserol (PTG), triasilgliserol teroksidasi monomerik (oxTAG), atau asid kaprilik (C8:0) telah dicadangkan sebagai indikator yang berpotensi untuk mengesan penyalahgunaan minyak terpakai. Oleh itu, kajian ini dilakukan untuk menguji kehadiran kompaun-kompaun tersebut di dalam minyak masak komersial, pembentukannya dalam pelbagai kajian pemanasan dan penggorengan, dan juga kehadiran kompaun ini dalam minyak kitar semula. Prosedur ini digunakan dalam memastikan kesesuaian kompaun tersebut dijadikan indeks kualiti bagi mengesan penyalahgunaan minyak terpakai atau kitar semula.

Dalam kajian pertama, sejumlah 23 sampel minyak masak komersial yang diperolehi dari pasaran Malaysia telah dibeli dan dibahagikan kepada tiga kategori utama, iaitu minyak sawit olein tulen, minyak sawit olein campuran, dan minyak sawit olein dalam bungkusan plastik. Keputusan menunjukkan jumlah kompaun polar (TPC) untuk semua sampel minyak masak segar didapati berada di dalam had selamat untuk penggunaan awam (< 25% kompaun polar) seperti yang ditetapkan oleh negara-negara Eropah. Tiada triasilgliserol (TAG) oligomer, asid epoksi, asid keto, dan asid hidroksi dapat dikesan di dalam semua sampel minyak masak segar.

Dalam kajian kedua, kajian pemanasan terkawal telah dijalankan. RBDPO telah dipanaskan secara berterusan selama 24 jam pada suhu 160 °C, 170 °C, and 180 °C, dengan sebahagian minyak diambil sebagai sampel setiap selang masa 4 jam bagi proses pemanasan kawalan. Jumlah oxTAG, TPC, dan PTG didapati bertambah secara ketara ($p < 0.05$) dengan peningkatan suhu dan masa pemanasan. Selepas proses pemanasan ini,

pembentukan asid epoksi adalah lebih tinggi berbanding asid keto dan asid hidroksi. Walau bagaimanapun, kandungan TPC telah melebihi had maksimum dan tidak selamat untuk kegunaan pengguna (>25% kompaun polar). Selain itu, asid kaprilik yang tidak dijumpai dalam sampel minyak masak segar didapati telah terbentuk dalam jumlah yang ketara selepas kajian pemanasan kawalan.

Dalam kajian ketiga, dua jenis makanan telah dipilih untuk kajian penggorengan, iaitu hirisan ubi kentang (SP) dan ketulan dada ayam (CBM). Secara keseluruhannya, proses penggorengan telah dilakukan selama 200 min/sehari sepanjang 7 hari secara berterusan dengan menggunakan RBDPO pada suhu 180 °C tanpa penambahan kuantiti minyak. Pembentukan jumlah TPC, PTG, dan asid kaprilik didapati lebih tinggi dalam RBDPO yang digoreng dengan SP berbanding CBM. Jumlah TPC di dalam RBDPO juga melepasi had maksimum dan tidak selamat untuk pengguna (> 25% kompaun polar) pada hari penggorengan yang ketujuh. Di samping itu, pembentukan asid epoksi, asid keto, dan asid hidroksi adalah lebih tinggi dalam RBDPO yang digoreng dengan CBM berbanding SP.

Seterusnya, sampel minyak masak yang digunakan untuk kajian pemanasan dan penggorengan di dalam kajian kedua dan ketiga telah dihantar untuk proses penapisan minyak bagi mensimulasikan penghasilan minyak kitar semula. Selepas proses penapisan minyak, jumlah PTG, TAG oligomer, dan dimer telah menunjukkan peningkatan yang ketara ($p < 0.05$). Jumlah oxTAG, asid lemak bebas (FFA), nilai peroksida (PV), dan nilai p-anisidin (AV) telah berkurangan dalam RBDPO kitar semula selepas proses penapisan. Dalam peringkat terakhir dalam kajian ini, kombinasi spektroskopi FT-NIR dan kemometrik telah digunakan untuk menentukan kuantiti produk thermo-oksidatif yang terbentuk di dalam minyak masak terpakai seperti PTG, oxTAG, dan TPC dengan pantas. Tiga model *partial least square regression* (PLS) telah dibina dengan ketepatan penentukuran yang tinggi.

Kesimpulannya, beberapa penunjuk kualiti berpotensi yang dicadangkan seperti PTG, oxTAG, dan asid kaprilik, telah dapat dijumpai di dalam sampel minyak kitar semula. Penemuan ini membuktikan kesesuaian penggunaan parameter tersebut sebagai indeks kualiti untuk mengesan penyalahgunaan minyak masak kerana kompaun-kompaun ini tidak dijumpai di dalam minyak masak segar. Melalui penemuan di dalam kajian ini, adalah diharapkan supaya kawalan penyalahgunaan minyak sawit olein terpakai dan kitar semula dapat ditingkatkan bagi melindungi kesihatan dan keselamatan pengguna.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest appreciation to my main supervisor, Prof. Dr. Tan Chin Ping for his excellent guidance, continuous support, patience, and motivation throughout my PhD research journey. His constructive and insightful comments and corrections made during the review of my thesis and manuscripts really helped me a lot in improving my work.

Besides, my gratitude is extended to my co-supervisors, Prof. Dr. Lai Oi Ming and Assoc. Prof. Dr. Faridah Abas for their great engagement and support throughout this research project, and their immense knowledge to help broaden my research perspectives. Special thanks to Prof Lai for allowing me to run the gas chromatography and using some other facilities in her research laboratory.

I would also like to thank Prof. Dr. Hasanah Mohd Ghazali for her kind support for me to run the high-performance liquid chromatography in her laboratory. My sincere thanks also go to Sime Darby Research, Golden Jomalina Food Industries Sdn. Bhd., Banting, exclusively to Mr. Radha Krishnan, for the use of the oil refinery unit and some other equipments available in their laboratory. Furthermore, I would also like to thank Mr. Kenneth Way and Mr. Patrick Lim from Perkin Elmer Sdn. Bhd. for their arrangements for me to use their FT-NIR spectroscopy unit and granted me the access to use their multivariate statistical software.

I would like to thank the Ministry of Higher Education (MOHE) for providing me the PhD scholarship as financial support throughout my PhD study. Also, not forgetting the laboratory staffs and research officers that I met along the way throughout my research journey, for their kindness and technical assistance during various laboratory tasks. I would also like to take this opportunity to thank my fellow labmates and friends for their valuable help, support, and joy during my study. Last but not least, I wish to thank my beloved parents and family for their unconditional support, love, and encouragement throughout my successful completion of my PhD studies.

I certify that a Thesis Examination Committee has met on 2 May 2019 to conduct the final examination of Khor Yih Phing on her thesis entitled "Evaluation and Development of Quality Indices for Adulteration in Palm Oil Industry by Used and Recycled Oils" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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- the research conducted and the writing of this thesis was under our supervision
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Name of Member of Supervisory Committee :Lai Oi Ming

Signature :__________________
Name of Member of Supervisory Committee :Faridah binti Abas

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
AV	*p*-anisidine value
BPO	Blended palm olein
CBM	Chicken breast meat
CPO	Crude palm oil
DAG	Diacylglycerol
FAME	Fatty acid methyl ester
FFA	Free fatty acid
FO	Fresh oil
FTIR	Fourier transform infrared
FT-NIR	Fourier transform-near infrared
GC	Gas chromatography
GC-FID	Gas chromatography-flame ionization detector
HCA	Hierarchical clustering analysis
HRGC	High resolution gas chromatography
HPLC	High-performance liquid chromatography
HPSEC	High-performance size-exclusion chromatography
KNN	K-nearest neighbor
LDA	Linear discriminant analysis
MUFA	Monounsaturated fatty acid
NMR	Nuclear magnetic resonance
oxTAG	Monomeric oxidized triacylglycerol
PAH	Polycyclic aromatic hydrocarbon
PC	Principal component

PCA	Principal component analysis
PFAD	Palm fatty acid distillate
PLS	Partial least squares
PO	Packet pure palm olein
PPO	Pure palm olein
PTG	Polymerized triacylglycerol
PTFE	Polytetrafluoroethylene
PV	Peroxide value
PUFA	Polyunsaturated fatty acid
RBDPO	Refined, bleached, and deodorized palm olein
RF	Random forest
RMSECV	Root mean square error for cross-validation
RMSEP	Root mean square error of prediction
RO	Recycled oil
ROOH	Alkyl hydroperoxides
ROOR	Dialkyl peroxides
SIMCA	Soft independent modeling of class analogy
SP	Sliced potatoes
SPE	Solid-phase extraction
SVM	Support vector machine
TAG	Triacylglycerol
TBME	*tert*-butyl methyl ether
THF	Tetrahydrofuran
TOTOX	Total oxidation value
TPC	Total polar compound

CHAPTER 1

INTRODUCTION

1.1 Research background for adulteration of used oils

Research shows that edible fats and oils are one of the foods that are most frequently counterfeited (Figure 1.1) (Moore et al., 2012). The use of adulterated edible oil in our food system is a hot topic among the food safety issues at present, as it poses a major threat toward the public health. There are many methods of adulteration, for instance, edible oil, which has a valuable composition and nutritional value, is generally expensive; therefore, to maximize profit, unscrupulous producers or manufacturers tend to adulterate the oil with cheaper or lower-quality edible oils (Akin et al., 2019).

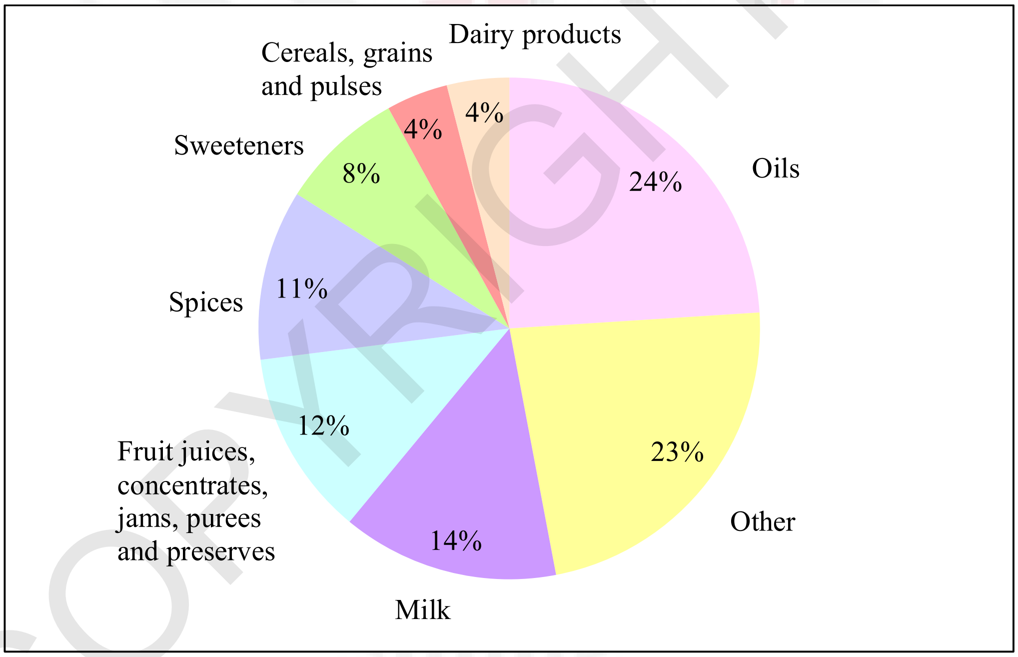

Figure 1.1: Percentage of food fraud cases from 1980 until 2010 (Moore et al., 2012)**.**

In addition, recently there have been many cases of adulteration of refined used oil or recycled oil in our food chain system. Recycled oils are reused; in other words, the collected used oils are further subjected to a complete refining process and then repackaged and resold. The presence of recycled oil in any form of food is illegal, and the recycled oil may impose harmful effects upon humans (Lu and Wu, 2014). Used oils are found to contain a huge amount of oxidized lipids which have been claimed to exert negative biological effects. It is suggested that a substantial amount of these oxidized lipids will still retain in the oil regardless of the refining process of used oil. In general, oxidized lipids have been implicated in numerous diseases, such as atherosclerosis, liver damage, intestinal tumours, acute inflammation or adult respiratory distress syndrome (Brühl et al., 2016; Marmesat et al., 2008a). These compounds also showed high toxicity and high digestibility (Berdeaux et al., 2008; Brühl et al., 2016). High intake of oxidation products can attribute to cancer and impairment of metabolic functions, but more data are needed on the intake of these compounds to see if the intake is sufficient to produce these adverse health effects (Kanner and Lapidot, 2001). In addition, polychlorinated biphenyls (PCBs), dioxins, arsenic, lead, aflatoxin, benzopyrene, and pesticide residue might be present in recycled oil and they may cause major public threat and will cause major disruption to the food supply.

To the best of our knowledge, currently there are still no established methods for detection of recycled oil. It is difficult to determine the degree of adulteration by simply referring to fatty acid composition and oxidation products, for example, or to free fatty acids (FFAs), peroxide values (PVs), ultraviolet specific extinction coefficients, and *p*-anisidine values (AVs) because eventually the recycled oil will go through the refining process before packaging. During the oil refining process, compounds that possess lower molecular weight or high volatility generally will be eliminated, especially during the deodorization stage (Riyadi et al., 2016), because during the deodorization step, the synergistic effects resulting from the combination of low vacuum, high temperature, and superheated steam are efficient in stripping the volatile components from the oil (FAO, 1994). Therefore, for our initial hypothesis, thermo-oxidative products that are nonvolatile and possess higher molecular weight that are generated during the oil degradation process may be proposed to be potential indicators to trace the adulteration of recycled oil.

In this scenario, special focus has been placed on three important quality parameters, which are monomeric oxidized triacylglycerols (oxTAGs), polymerized triacylglycerols (PTGs), and caprylic acid concentration because they are nonvolatile compounds formed in great amount when oils are subjected to elevated temperature for long period in the presence of oxygen. In a total of 5 working chapters, the scope of this study will basically focus on the identification and detection of these proposed quality parameters in different oil samples that underwent different treatments. As palm olein is a relatively inexpensive edible oil and is widely consumed as a major lipid source in developing countries, it was selected as the main sample for this study.

In the first stage, the safety and quality of the commercial palm olein samples were evaluated, and the emphasis was on the presence of the proposed indicators in these fresh oil samples. The PTG, oxTAG, and caprylic acid are thermo-oxidative alteration products that are formed during the oil deterioration process. Normally, these analyses are conducted on used oil samples, but now the evaluation was carried out on selected fresh oil samples as these nonvolatile compounds are not supposed to be present in fresh oil samples.

Next, palm olein was heated at various temperatures to serve as a fundamental study to provide more insight related to the extent of overall oxidative deterioration and the formation of the proposed quality parameters in the heated oil-without-food system. The correlations among all the analytical parameters were also conducted. The impacts of different raw materials used for deep-frying on the formation of PTG, oxTAG, and caprylic acid were also investigated. The oxidation and polymerization processes were examined in depth to evaluate the discarding point of the oil. The formation of these polar products must be closely monitored, as they will affect the functional, sensory, and nutritional properties of the frying oil. A significant amount of the oxidized frying oil will be absorbed into the fried foods and eventually ingested into the human body. These thermo-oxidative products are generally recognized as threats if consumed in large quantities due to their detrimental effects.

The used oil samples in second and third stage were further subjected to an oil refining process to simulate the production of recycled oil. Then, the quality of the recycled oil was evaluated and compared with the fresh and used oil samples. Additionally, at this stage, the emphasis was on the presence of PTG, oxTAG, and caprylic acid in recycled oil samples to justify the suitability of the proposed quality parameters to be used as potential indicators to trace the adulteration of recycled oil. Furthermore, a rapid method to quantify the PTG, oxTAG, and total polar compounds (TPCs) was developed by using Fourier transform near-infrared (FT-NIR) spectroscopy coupled with the partial least squares (PLS) regression method. This rapid method is important to replace the conventional method in evaluating the polar fractions, as the common method is laborious, requires skillful operators, is less economically effective, and is not environmentally friendly.

It is our hope to develop much better indices of quality to trace the adulteration of recycled oils to safeguard the health of the general public and the rights of consumers. As a result of the advances in analytical methods, and the new challenges created by fraudsters, official methods and trade standards should be periodically revised and updated.

1.2 Research objectives

The objectives of this study were as follows:

1. To evaluate the physicochemical properties and polar lipid fraction of commercial palm olein samples available in the Malaysian market.
2. To identify the effect of different heating times and temperatures on the physicochemical properties and formation of polar lipid fraction in palm olein during a controlled heating study.
3. To investigate the effect of frying different foods on the physicochemical properties and formation of polar lipid fraction in palm olein during deep-fat frying.
4. To compare the physicochemical properties and polar lipid fraction of fresh, used, and recycled palm olein.
5. To develop a rapid method for PTG, oxTAG, and TPC quantification using FT-NIR spectroscopy coupled with chemometrics.

REFERENCES

Abbas Ali, M., Hadi Bin Mesran, M., Abd Latip, R., Hidayu Othman, N. and Nik Mahmood, N. A. (2016). Effect of microwave heating with different exposure times on the degradation of corn oil. *International Food Research Journal* 23(2): 842-848.

Abidi, S. L. and Rennick, K. A. (2003). Determination of nonvolatile components in polar fractions of rice bran oils. *Journal of the American Oil Chemists' Society* 80(11): 1057-1062.

Ahmad Tarmizi, A. H., Hishamuddin, E. and Abd Razak, R. A. (2019). Impartial assessment of oil degradation through partitioning of polar compounds in vegetable oils under simulated frying practice of fast food restaurants. *Food Control* 96: 445-455.

Ahmad Tarmizi, A. H. and Ismail, R. (2008). Comparison of the frying stability of standard palm olein and special quality palm olein. *Journal of the American Oil Chemists' Society* 85(3): 245-251.

Ahmad Tarmizi, A. H., Ismail, R. and Kuntom, A. (2016). Effect of frying on the palm oil quality attributes - a review. *Journal of Oil Palm Research* 28: 143-153.

Akin, G., Karuk Elmas, Ş. N., Arslan, F. N., Yılmaz, İ. and Kenar, A. (2019). Chemometric classification and quantification of cold pressed grape seed oil in blends with refined soybean oils using attenuated total reflectance–mid infrared (ATR–MIR) spectroscopy. *LWT - Food Science and Technology* 100: 126-137.

Aladedunye, F. A. (2015). Curbing thermo-oxidative degradation of frying oils: Current knowledge and challenges. *European Journal of Lipid Science and Technology* 117(11): 1867-1881.

Aladedunye, F. A. and Przybylski, R. (2009). Degradation and nutritional quality changes of oil during frying. *Journal of the American Oil Chemists' Society* 86(2): 149-156.

Ali Rehab, F. M. and El Anany, A. M. (2012). Physicochemical studies on sunflower oil blended with cold pressed tiger nut oil during deep frying process. *Grasas y Aceites* 63(4): 455-465.

Alvarenga, B. R., Xavier, F. A. N., Soares, F. L. F. and Carneiro, R. L. (2018). Thermal Stability Assessment of Vegetable Oils by Raman Spectroscopy and Chemometrics. *Food Analytical Methods* 11(7): 1969-1976.

Aniolowska, M. A. and Kita, A. M. (2015). The effect of raw materials on thermo-oxidative stability and glycidyl ester content of palm oil during frying. *Journal of the Science of Food and Agriculture* 96(6): 2257-2262.

Aniołowska, M. A. and Kita, A. M. (2016). The effect of frying on glycidyl esters content in palm oil. *Food Chemistry* 203: 95-103.

AOCS (2013). Official methods and recommended practices. (6, ed.). Champaign, Illinois: American Oil Chemists' Society (Method Cc 91-48).

AOCS (2013a). Official methods and recommended practices. (6, ed.). Champaign, Illinois: American Oil Chemists' Society (Method Cd 8b-90).

AOCS (2013b). Official methods and recommended practices. (6, ed.). Champaign, Illinois: American Oil Chemists' Society (Method Cd 18-90).

Aparicio, R. and Aparicio-Ruíz, R. (2000). Authentication of vegetable oils by chromatographic techniques. *Journal of Chromatography A* 881(1): 93-104.

Arslan, F. N., Şapçı, A. N., Duru, F. and Kara, H. (2017). A study on monitoring of frying performance and oxidative stability of cottonseed and palm oil blends in comparison with original oils *International Journal of Food Properties* 20(3): 704-717.

Arvanitoyannis, I. S. and Kotsanopoulos, K. V. (2016). Methods and techniques for detecting food authenticity in authenticity of foods of animal origin. Boca Raton: CRC Press Taylor & Francis Group.

Azadmard-Damirchi, S. and Torbati, M. (2015). Adulterations in some edible oils and fats and their detection methods. *Journal of Food Quality and Hazards Control* 2: 38-44.

Azmil, H. A. T., Razali, I. and Ainie, K. (2016). Effect of frying on the palm oil quality attributes - a review. *Journal of Oil Palm Research* 28: 143-153.

Baltacıoğlu, C. (2017). Effect of different frying methods on the total trans fatty acid content and oxidative stability of oils. *Journal of the American Oil Chemists' Society* 94(7): 923-934.

Bansal, G., Zhou, W. B., Barlow, P. J., Joshi, P. S., Lo, H. L. and Chung, Y. K. (2010a). Review of rapid tests available for measuring the quality changes in frying oils and comparison with standard methods. *Critical Reviews in Food Science and Nutrition* 50(6): 503-514.

Bansal, G., Zhou, W. B., Barlow, P. J., Lo, H. L. and Neo, F. L. (2010b). Performance of palm olein in repeated deep frying and controlled heating processes. *Food Chemistry* 121(2): 338-347.

Bastida, S. and Sánchez-Muniz, F. J. (2002). Polar content vs. TAG oligomer content in the frying-life assessment of monounsaturated and polyunsaturated oils used in deep-frying. *Journal of the American Oil Chemists' Society* 79(5): 447-451.

Berdeaux, O., Dutta, P. C., Dobarganes, M. C. and Sebedio, J. L. (2009). Analytical methods for quantification of modified fatty acids and sterols formed as a result of processing. *Food Analytical Methods* 2(1): 30-40.

Berdeaux, O., Dutta, P. C., Dobarganes, M. C. and Sébédio, J. L. (2008). Analytical Methods for Quantification of Modified Fatty Acids and Sterols Formed as a Result of Processing. *Food Analytical Methods* 2(1): 30-40.

Brühl, L. (2014). Fatty acid alterations in oils and fats during heating and frying. *European Journal of Lipid Science and Technology* 116(6): 707-715.

Brühl, L., Weisshaar, R. and Matthäus, B. (2016). Epoxy fatty acids in used frying fats and oils, edible oils and chocolate and their formation in oils during heating. *European Journal of Lipid Science and Technology* 118(3): 425-434.

Bulut, E. and Yılmaz, E. (2010). Comparison of the frying stability of sunflower and refined olive pomace oils with/without adsorbent treatment. *Journal of the American Oil Chemists' Society* 87(10): 1145-1153.

Büning-Pfaue, H. and Kehraus, S. (2001). Application of near infrared spectroscopy (NIRS) in the analysis of frying fats. *European Journal of Lipid Science and Technology* 103(12): 793-797.

Calero, A. M., Munoz, E., Perez-Marin, D., Riccioli, C., Perez, L. and Garrido-Varo, A. (2018). Evolution of frying oil quality using fourier transform near-infrared (FT-NIR) spectroscopy. *Applied Spectroscopy* 0(0): 1-13.

Cao, W. M., Zhang, K. Y., Xue, B., Chen, F. X., Jin, Q. Z. and Wang, X. G. (2013). Determination of oxidized triacylglycerol polymers by preparative flash chromatography and high-performance size-exclusion chromatography. *Asian Journal of Chemistry* 25(16): 9189-9194.

Casarotti, S. N. and Jorge, N. (2012). Antioxidant activity of rosemary extract in soybean oil under thermoxidation. *Journal of Food Processing and Preservation* 38(1): 136-145.

Cert, A., Moreda, W. and Pérez-Camino, M. C. (2000). Chromatographic analysis of minor constituents in vegetable oils. *Journal of Chromatography A* 881(1): 131-148.

Che Man, Y. B. and Jaswir, I. (2000). Effect of rosemary and sage extracts on frying performance of refined, bleached and deodorized (RBD) palm olein during deep-fat frying. *Food Chemistry* 69: 301-307.

Chemat, S. (2017). Edible oils: extraction, processing, and applications. Florida: CRC Press.

Chen, X., Yu, X., Wang, Y., Yang, Y. and Zhang, J. (2015). Determination of polar components in frying oils by Fourier-transform near-infrared spectroscopy. *Journal of Oleo Science* 64(3): 255-261.

Choe, E. and Min, D. B. (2006). Mechanisms and Factors for Edible Oil Oxidation. *Comprehensive Reviews in Food Science and Food Safety* 5(4): 169-186.

Choe, E. and Min, D. B. (2007). Chemistry of deep-fat frying oils. *Journal of Food Science* 72(5): 77-86.

Christian, G. (2014). Fundamentals of the frying process. *European Journal of Lipid Science and Technology* 116(6): 669-674.

Cohn, J. S. (2002). Oxidized fat in the diet, postprandial lipaemia and cardiovascular disease. *Current Opinion in Lipidology* 13(1): 19-24.

Cozzolino, D., Cynkar, W. U., Shah, N. and Smith, P. (2011). Multivariate data analysis applied to spectroscopy: Potential application to juice and fruit quality. *Food Research International* 44(7): 1888-1896.

Cozzolino, D., Murray, I., Chree, A. and Scaife, J. R. (2005). Multivariate determination of free fatty acids and moisture in fish oils by partial least-squares regression and near-infrared spectroscopy. *LWT - Food Science and Technology* 38(8): 821-828.

Crosa, M. J., Skerl, V., Cadenazzi, M., Olazábal, L., Silva, R., Suburú, G. and Torres, M. (2014). Changes produced in oils during vacuum and traditional frying of potato chips. *Food Chemistry* 146: 603-607.

De Greyt, W. (2018). Deodorization. In). Illinois: The AOCS Library.

Department of Standards Malaysia (2007). Palm olein - specification (second revision). In Malaysian standard (MS 816:2007), Malaysia: Standards Malaysia.

Dobarganes, C. and Marquez-Ruiz, G. (2003). Oxidized fats in foods. *Current Opinion in Clinical Nutrition & Metabolic Care* 6(2): 157-163.

Dobarganes, C. and Márquez-Ruiz, G. (2013). Analysis of used frying oils. *Lipid Technology* 25(7): 159-162.

Donner, M. G. and Richter, W. O. (2000). 3rd International symposium on deep-fat frying — optimal operation. *European Journal of Lipid Science and Technology* 102(4): 306-308.

Du, R., Lai, K. Q., Xiao, Z. Q., Shen, Y. G., Wang, X. C. and Huang, Y. Q. (2012). Evaluation of the quality of deep frying oils with Fourier transform near-infrared and mid-infrared spectroscopy. *Journal of Food Science* 77(2): 261-266.

Endo, Y. (2018). Analytical methods to evaluate the quality of edible fats and oils: The JOCS standard methods for analysis of fats, oils and related materials (2013) and advanced methods. *Journal of Oleo Science* 67(1): 1-10.

Enríquez-Fernández, B. E., Álvarez de la Cadena y Yañez, L. and Sosa-Morales, M. E. (2011). Comparison of the stability of palm olein and a palm olein/canola oil blend during deep-fat frying of chicken nuggets and French fries. *International Journal of Food Science & Technology* 46(6): 1231-1237.

Erickson, D. R. (1990). Edible fats and oils processing: basic principles and modern practices. Champaign, Illinois: American Oil Chemists' Society.

FAO. (1994). Fats and oils in human nutrition (Chapter 5: Processing and refining edible oils). In). Italy: Food and Agriculture Organization of the United Nations.

Farhoosh, R., Einafshar, S. and Sharayei, P. (2009). The effect of commercial refining steps on the rancidity measures of soybean and canola oils. *Food Chemistry* 115(3): 933-938.

Feng, H. X., Sam, R., Jiang, L. Z., Li, Y. and Cao, W. M. (2016). High-performance size-exclusion chromatography studies on the formation and distribution of polar compounds in camellia seed oil during heating. *Journal of Zhejiang University Science B* 17(11): 882-891.

Fullana, A., Carbonell-Barrachina, Á. A. and Sidhu, S. (2004). Volatile aldehyde emissions from heated cooking oils. *Journal of the Science of Food and Agriculture* 84(15): 2015-2021.

Gertz, C. (2000). Chemical and physical parameters as quality indicators of used frying fats. *European Journal of Lipid Science and Technology* 102: 566-572.

Gertz, C., Aladedunye, F. and Matthäus, B. (2014). Oxidation and structural decomposition of fats and oils at elevated temperatures. *European Journal of Lipid Science and Technology* 116(11): 1457-1466.

Gertz, C. and Behmer, D. (2014). Application of FT-NIR spectroscopy in assessment of used frying fats and oils. *European Journal of Lipid Science and Technology* 116(6): 756-762.

Gertz, C., Fiebig, H.-J. and Hancock, J. N. S. (2013). FT-near infrared (NIR) spectroscopy – Screening analysis of used frying fats and oils for rapid determination of polar compounds, polymerized triacylglycerols, acid value and anisidine value [DGF C-VI 21a (13)]. *European Journal of Lipid Science and Technology* 115(10): 1193-1197.

Gibon, V., Greyt, W. D. and Kellens, M. (2007). Palm oil refining. *European Journal of Lipid Science and Technology* 109: 315-335.

He, J., Xu, W., Shang, Y., Zhu, P., Mei, X., Tian, W. and Huang, K. (2013). Development and optimization of an efficient method to detect the authenticity of edible oils. *Food Control* 31(1): 71-79.

Inturrisi, L. (2013). Regulatory and food safety requirements for frying oil quality. Newcastle, Australia: Deep Frying Workshop.

Jacobsen, C. (2010). 6 - Understanding and reducing oxidative flavour deterioration in foods. In *E. A. Decker,* ed. Oxidation in Foods and Beverages and Antioxidant Applications, pp. 122-142. Woodhead Publishing.

Jaswir, I., Che Man, Y. B. and Kitts, D. D. (2000). Use of natural antioxidants in refined palm olein during repeated deep-fat frying. *Food Research International* 33(6): 501-508.

Ji, J., Liu, Y., Shi, L., Wang, N. and Wang, X. (2019). Effect of roasting treatment on the chemical composition of sesame oil. *LWT - Food Science and Technology* 101: 191-200.

Kalogeropoulos, N., Salta, F. N., Chiou, A. and Andrikopoulos, N. K. (2007). Formation and distribution of oxidized fatty acids during deep- and pan-frying of potatoes. *European Journal of Lipid Science and Technology* 109(11): 1111-1123.

Kanner, J. and Lapidot, T. (2001). The stomach as a bioreactor: dietary lipid peroxidation in the gastric fluid and the effects of plant-derived antioxidants. *Free Radical Biology and Medicine* 31(11): 1388-1395.

Karakaya, S. and Şimşek, Ş. (2011). Changes in total polar compounds, peroxide value, total phenols and antioxidant activity of various oils used in deep fat frying. *Journal of the American Oil Chemists' Society* 88(9): 1361-1366.

Karimi, S., Wawire, M. and Mathooko, F. M. (2017). Impact of frying practices and frying conditions on the quality and safety of frying oils used by street vendors and restaurants in Nairobi, Kenya. *Journal of Food Composition and Analysis* 62: 239-244.

Khosla, P. (2011). 6 - Nutritional characteristics of palm oil. In *G. Talbot,* ed. Reducing Saturated Fats in Foods, pp. 112-127. Cambridge: Woodhead Publishing.

Kong, F. and Singh, R. P. (2011). 12 - Advances in instrumental methods to determine food quality deterioration. In *D. Kilcast andP. Subramaniam,* ed. Food and Beverage Stability and Shelf Life, pp. 381-404. Cambridge: Woodhead Publishing.

Kushairi, A., Loh, S. K., Azman, I., Hishamuddin, E., Abdullah, M. O., Izuddin, Z. B. M. N., Razmah, G., Sundram, S. and Parveez, G. K. A. (2018). Oil palm economic performance in Malaysia and R&D progress in 2017. *Journal of Oil Palm Research* 30(2): 163-195.

Lai, O. M., Tan, C. P. and Akoh, C. C. (2012). Palm oil: production, processing, characterization, and uses. . *AOCS Press, Urbana, Illinois.*

Li, C. M., Kimura, F., Endo, Y., Maruyama, C. and Fujimoto, K. (2005). Deterioration of diacylglycerol- and triacylglycerol-rich oils during frying of potatoes. *European Journal of Lipid Science and Technology* 107(3): 173-179.

Li, X., Li, J., Wang, Y., Cao, P. and Liu, Y. (2017). Effects of frying oils' fatty acids profile on the formation of polar lipids components and their retention in French fries over deep-frying process. *Food Chemistry* 237: 98-105.

Li, X., Wu, G., Yang, F., Meng, L., Huang, J., Zhang, H., Jin, Q. and Wang, X. (2019). Influence of fried food and oil type on the distribution of polar compounds in discarded oil during restaurant deep frying. *Food Chemistry* 272: 12-17.

Liu, Y., Cheng, Y., Li, J., Wang, Y. and Liu, Y. (2018a). Epoxy stearic acid, an oxidative product derived from oleic acid, induces cytotoxicity, oxidative stress, and apoptosis in HepG2 cells. *Journal of Agricultural and Food Chemistry* 66(20): 5237-5246.

Liu, Y., Li, J., Cheng, Y. and Liu, Y. (2019). Effect of frying oils' fatty acid profile on quality, free radical and volatiles over deep-frying process: A comparative study using chemometrics. *LWT - Food Science and Technology* 101: 331-341.

Liu, Y., Wang, Y., Cao, P. and Liu, Y. (2018b). Quantitative determination of epoxy stearic acids derived from oxidized frying oil based on solid-phase extraction and gas chromatography. *LWT - Food Science and Technology* 92: 250-257.

Lopez-Diez, E. C., Bianchi G Fau - Goodacre, R. and Goodacre, R. (2003). Rapid quantitative assessment of the adulteration of virgin olive oils with hazelnut oils using Raman spectroscopy and chemometrics. *Journal of Agricultural and Food Chemistry* 51(21): 6145-6150.

Lu, F. and Wu, X. (2014). China food safety hits the "gutter". *Food Control* 41: 134-138.

Maggio, R. M., Cerretani, L., Chiavaro, E., Kaufman, T. S. and Bendini, A. (2010). A novel chemometric strategy for the estimation of extra virgin olive oil adulteration with edible oils. *Food Control* 21(6): 890-895.

Marmesat, S., Rodrigues, E., Velasco, J. and Dobarganes, C. (2007a). Quality of used frying fats and oils: comparison of rapid tests based on chemical and physical oil properties. *International Journal of Food Science & Technology* 42(5): 601-608.

Marmesat, S., Velasco, J. and Dobarganes, M. C. (2008a). Quantitative determination of epoxy acids, keto acids and hydroxy acids formed in fats and oils at frying temperatures. *J Chromatogr A* 1211(1-2): 129-134.

Marmesat, S., Velasco, J. and Dobarganes, M. C. (2008b). Quantitative determination of epoxy acids, keto acids and hydroxy acids formed in fats and oils at frying temperatures. *Journal of Chromatography A* 1211(1): 129-134.

Marmesat, S., Velasco, J., Márquez-Ruiz, G. and Dobarganes, M. C. (2007b). A rapid method for determination of polar compounds in used frying fats and oils. *Grasas y Aceites* 58(2): 179-184.

Márquez-Ruiz, G. and Dobarganes, C. (1996). Short-chain fatty acid formation during thermoxidation and frying. *Journal of the Science of Food and Agriculture* 70(1): 120-126.

Marquez-Ruiz, G., Dobarganes, M. C. and Erickson, M. D. (2006). Deep frying: chemistry, nutrition and practical applications. Champaign, Illinois: AOCS Press.

Marquez-Ruiz, G., Holgado, F., Garcia-Martinez, M. C. and Dobarganes, M. C. (2007). A direct and fast method to monitor lipid oxidation progress in model fatty acid methyl esters by high-performance size-exclusion chromatography. *Journal of Chromatography A* 1165(1-2): 122-127.

Márquez-Ruiz, G., Martín-Polvillo, M. and Dobarganes, M. C. (1996). Quantitation of oxidized triglyceride monomers and dimers as an useful measurement for early and advanced stages of oxidation. *Grasas y Aceites* 47: 48-53.

Maskan, M. and İ. Bağcı, H. (2003). The recovery of used sunflower seed oil utilized in repeated deep-fat frying process. *European Food Research and Technology* 218(1): 26-31.

Matthäus, B. (2010). 6 - Oxidation of edible oils. In *E. A. Decker, R. J. Elias andD. Julian McClements,* ed. Oxidation in foods and beverages and antioxidant applications, pp. 183-238. Woodhead Publishing.

Matthäus, B., Haase, N. U. and Unbehend, G. (2009). Chemical and sensory characteristics of products fried in high-oleic, low-linolenic rapeseed oil. *Journal of the American Oil Chemists' Society* 86(8): 799-808.

Mba, O. I., Dumont, M.-J. and Ngadi, M. (2015). Palm oil: Processing, characterization and utilization in the food industry – A review. *Food Bioscience* 10: 26-41.

Moore, J. C., Spink, J. and Lipp, M. (2012). Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010. *Journal of Food Science* 77(4): 118-126.

Moros, J., Garrigues, S. and Guardia, M. D. l. (2010). Vibrational spectroscopy provides a green tool for multi-component analysis. *Trends in Analytical Chemistry* 29(7): 578-591.

MPOB. (2010). The usual range of major fatty acids in commercial cooking oils. In): Official Portal of Malaysian Palm Oil Board.

Mubiru, E., Shrestha, K., Papastergiadis, A. and De Meulenaer, B. (2013). Improved gas chromatography-flame ionization detector analytical method for the analysis of epoxy fatty acids. *Journal of Chromatography A* 1318: 217-225.

Mubiru, E., Shrestha, K., Papastergiadis, A. and De Meulenaer, B. (2014). Development and validation of a gas chromatography–flame ionization detection method for the determination of epoxy fatty acids in food matrices. *Journal of Agricultural and Food Chemistry* 62(13): 2982-2988.

Nagachinta, S. and Akoh, C. C. (2012). Enrichment of palm olein with long chain polyunsaturated fatty acids by enzymatic acidolysis. *LWT - Food Science and Technology* 46(1): 29-35.

Nayak, P. K., Dash, U., Rayaguru, K. and Krishnan, K. R. (2016). Physico-chemical changes during repeated frying of cooked oil: A review. *Journal of Food Biochemistry* 40(3): 371-390.

Nicolaï, B. M., Beullens, K., Bobelyn, E., Peirs, A., Saeys, W., Theron, K. I. and Lammertyn, J. (2007). Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: A review. *Postharvest Biology and Technology* 46(2): 99-118.

Nogueira, M. S., Scolaro, B., Milne, G. L. and Castro, I. A. (2019). Oxidation products from omega-3 and omega-6 fatty acids during a simulated shelf life of edible oils. *LWT - Food Science and Technology* 101: 113-122.

Noor Lida, H. M. D., Sundram, K., Siew, W. L., Aminah, A. and Mamot, S. (2002). TAG composition and solid fat content of palm oil, sunflower oil, and palm kernel olein belends before and after chemical interesterification. *Journal of the American Oil Chemists' Society* 79(11): 1137-1144.

Nor, F. M., Mohamed, S., Idris, N. A. and Ismail, R. (2008). Antioxidative properties of *Pandanus amaryllifolius* leaf extracts in accelerated oxidation and deep frying studies. *Food Chemistry* 110(2): 319-327.

O'Brien, R. D. (2010). Fats and oils: Formulating and processing for applications. (3rd, ed.). Florida: CRC Press.

Okogeri, O. (2013). Adulteration of crude palm oil with red dye from the leaf sheath of sorghum bicolor. *Food Science and Quality Management* 17: 1-6.

Osawa, C. C. and Gonçalves, L. A. G. (2012). Deep-fat frying of meat products in palm olein. *Food Science and Technology* 32(4): 804-811.

Rahman, A. (2012). Application of fourier transform infrared spectroscopy for quality control of pharmaceutical products: a review. *Indonesian Journal of Pharmacy* 23(1): 1-8.

Riyadi, A. H., Muchtadi, T. R., Andarwulan, N. and Haryati, T. (2016). Pilot plant study of red palm oil deodorization using moderate temperature. *Agriculture and Agricultural Science Procedia* 9: 209-216.

Rodrigues Machado, E., Marmesat, S., Abrantes, S. and Dobarganes, C. (2007). Uncontrolled variables in frying studies: differences in repeatability between thermoxidation and frying experiments. *Grasas y Aceites* 58(3): 6.

Rohman, A. (2017). Infrared spectroscopy for quantitative analysis and oil parameters of olive oil and virgin coconut oil: a review. *International Journal of Food Properties* 20(7): 1447-1456.

Rohman, A., Triyana, K., Sismindari and Erwanto, Y. (2012). Differentiation of lard and other animal fats based on triacylglycerols composition and principal component analysis. *International Food Research Journal* 19(2): 475-479.

Ruiz-Mendez, M. V. and Dobarganes, M. C. (2018). Oil refining. AOCS Lipid Library: The American Oil Chemists' Society.

Saguy, I. S. and Dana, D. (2003). Integrated approach to deep fat frying: engineering, nutrition, health and consumer aspects. *Journal of Food Engineering* 56(2): 143-152.

Salzer, R. (2008). Practical guide to interpretive near-infrared spectroscopy. By Jerry Workman, Jr. and Lois Weyer. *Angewandte Chemie International Edition* 47(25): 4628-4629.

Sathianathan, R. V., Kannapiran, A., Govindan, J. and Periasamy, N. (2014). Profiling of fatty acid compositional alterations in edible oils upon heating using gas chromatography. *Journal of Physical Science* 25(2): 1-14.

Schroeder, M. T., Becker, E. M. and Skibsted, L. H. (2006). Molecular mechanism of antioxidant synergism of tocotrienols and carotenoids in palm oil. *Journal of Agricultural and Food Chemistry* 54(9): 3445-3453.

Sebastian, A., Ghazani, S. M. and Marangoni, A. G. (2014). Quality and safety of frying oils used in restaurants. *Food Research International* 64: 420-423.

Sharayei, P. and Farhoosh, R. (2016). Improved frying stability of canola oil blended with palm olein and virgin olive oils as affected by bene kernel oil and its unsaponifiable matter. *European Journal of Lipid Science and Technology* 118(10): 1495-1506.

Sivakanthan, S., Jayasooriya, A. P. and Madhujith, T. (2019). Optimization of the production of structured lipid by enzymatic interesterification from coconut (*Cocos nucifera*) oil and sesame (*Sesamum indicum*) oil using Response Surface Methodology. *LWT - Food Science and Technology* 101: 723-730.

Song, J., Kim, M.-J., Kim, Y.-J. and Lee, J. (2017). Monitoring changes in acid value, total polar material, and antioxidant capacity of oils used for frying chicken. *Food Chemistry* 220: 306-312.

Sumathi, S., Chai, S. P. and Mohamed, A. R. (2008). Utilization of oil palm as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews* 12(9): 2404-2421.

Tabee, E., Jägerstad, M. and Dutta, P. C. (2009). Frying quality characteristics of french fries prepared in refined olive oil and palm olein. *Journal of the American Oil Chemists' Society* 86(9): 885-893.

Tan, C.-H., Ghazali, H. M., Kuntom, A., Tan, C.-P. and Ariffin, A. A. (2009). Extraction and physicochemical properties of low free fatty acid crude palm oil. *Food Chemistry* 113(2): 645-650.

Tan, Y.-A., Kuntom, A., Lee, C. K. and Low, K. S. (2004). Comparative evaluation of palm oil color measurement using a prototype palm oil colorimeter. *Journal of the American Oil Chemists' Society* 81(8): 733-736.

Torrecilla, J. S., García, J., García, S. and Rodríguez, F. (2011). Application of lag-k autocorrelation coefficient and the TGA signals approach to detecting and quantifying adulterations of extra virgin olive oil with inferior edible oils. *Analytica Chimica Acta* 688(2): 140-145.

Valdivielso, I., Bustamante, M. Á., Ruiz de Gordoa, J. C., Nájera, A. I., de Renobales, M. and Barron, L. J. R. (2015). Simultaneous analysis of carotenoids and tocopherols in botanical species using one step solid–liquid extraction followed by high performance liquid chromatography. *Food Chemistry* 173: 709-717.

Velasco, J., Berdeaux, O., Márquez-Ruiz, G. and Dobarganes, M. C. (2002). Sensitive and accurate quantitation of monoepoxy fatty acids in thermoxidized oils by gas–liquid chromatography. *Journal of Chromatography A* 982(1): 145-152.

Velasco, J., Marmesat, S., Bordeaux, O., Marquez-Ruiz, G. and Dobarganes, C. (2014). Formation and evolution of monoepoxy fatty acids in thermoxidized olive and sunflower oils and quantitation in used frying oils from restaurants and fried-food outlets. *Journal of Agricultural and Food Chemistry* 52(14): 4438-4443.

Velasco, J., Marmesat, S., Márquez-Ruiz, G. and Dobarganes, M. C. (2004). Formation of short-chain glycerol-bound oxidation products and oxidised monomeric triacylglycerols during deep-frying and occurrence in used frying fats. *European Journal of Lipid Science and Technology* 106(11): 728-735.

Waghmare, A., Patil, S., LeBlanc, J. G., Sonawane, S. and Arya, S. S. (2018). Comparative assessment of algal oil with other vegetable oils for deep frying. *Algal Research* 31: 99-106.

Wang, F., Jiang, L., Zhu, X. and Hou, J. (2013). Effects of frying on polar material and free fatty acids in soybean oils. *International Journal of Food Science & Technology* 48(6): 1218-1223.

Wasowicz, E., Gramza, A., Hes, M., Jelen, H. H., Korczak, J., Malecka, M., Mildner-Szkudlarz, S., Rudzinska, M., Somotyja, U. and Zawirska-Wojtasiak, R. (2004). Oxidation of lipids in food. *Polish Journal of Food and Nutrition Sciences* 13/54(1): 87-100.

Weisshaar, R. (2014). Quality control of used deep-frying oils. *European Journal of Lipid Science and Technology* 116(6): 716-722.

Wu, S.-J. and Ng, L. T. (2007). Antioxidant and antihepatoma activities of palm oil extract *Journal of Food Lipids* 14(2): 122-137.

Xu, L., Xu, X., Xiong, H., Chen, L. and Li, Y. (2014). Rapid detection of vegetable cooking oils adulterated with inedible used oil using fluorescence quenching method with aqueous CTAB-coated quantum dots. *Sensors and Actuators B: Chemical* 203: 697-704.

Yen, G.-C., Shao, C.-H., Chen, C.-J. and Duh, P.-D. (1997). Effects of antioxidant and cholesterol on smoke point of oils. *LWT - Food Science and Technology* 30(7): 648-652.

Yi, J., Andersen, M. L. and Skibsted, L. H. (2011). Interactions between tocopherols, tocotrienols and carotenoids during autoxidation of mixed palm olein and fish oil. *Food Chemistry* 127(4): 1792-1797.

Yu, K. S., Cho, H. and Hwang, K. T. (2018). Physicochemical properties and oxidative stability of frying oils during repeated frying of potato chips. *Food Science and Biotechnology* 27(3): 651-659.

Zhang, L., Li, P., Sun, X., Wang, X., Xu, B., Wang, X., Ma, F., Zhang, Q. and Ding, X. (2014). Classification and adulteration detection of vegetable oils based on fatty acid profiles. *Journal of Agricultural and Food Chemistry* 62(34): 8745-8751.

Zhang, Q., Liu, C., Sun, Z., Hu, X. S., Shen, Q. and Wu, J. H. (2012a). Authentication of edible vegetable oils adulterated with used frying oil by Fourier Transform Infrared Spectroscopy. *Food Chemistry* 132(3): 1607-1613.

Zhang, Q., Qin, W., Li, M., Shen, Q. and Saleh, A. S. M. (2015). Application of chromatographic techniques in the detection and identification of constituents formed during food frying: A review. *Comprehensive Reviews in Food Science and Food Safety* 14(5): 601-633.

Zhang, Q., Saleh, A. S. M., Chen, J. and Shen, Q. (2012b). Chemical alterations taken place during deep-fat frying based on certain reaction products: A review. *Chemistry and Physics of Lipids* 165(6): 662-681.

Zhao, X., Ma, F., Li, P., Li, G., Zhang, L., Zhang, Q., Zhang, W. and Wang, X. (2015). Simultaneous determination of isoflavones and resveratrols for adulteration detection of soybean and peanut oils by mixed-mode SPE LC–MS/MS. *Food Chemistry* 176: 465-471.

Zhao, Y., Chen, C. and Zhao, B. (2018). Is oil temperature a key factor influencing air pollutant emissions from Chinese cooking? *Atmospheric Environment* 193: 190-197.

Zribi, A., Jabeur, H., Aladedunye, F., Rebai, A., Matthäus, B. and Bouaziz, M. (2014). Monitoring of quality and stability characteristics and fatty acid compositions of refined olive and seed oils during repeated pan- and deep-frying using GC, FT-NIRS, and chemometrics. *Journal of Agricultural and Food Chemistry* 62(42): 10357-10367.