UNIVERSITI PUTRA MALAYSIA

FORMATION, MITIGATION AND ANALYSIS OF 3-MCPD AND GLYCIDYL ESTERS DURING DEEP-FAT FRYING OF POTATO CHIPS AND CHICKEN BREAST MEAT USING RBD PALM OLEIN

WONG YU HUA

FSTM 2016 30

FORMATION, MITIGATION AND ANALYSIS OF 3-MCPD AND GLYCIDYL ESTERS DURING DEEP-FAT FRYING OF POTATO CHIPS AND CHICKEN BREAST MEAT USING RBD PALM OLEIN

By

WONG YU HUA

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

September 2016

This thesis is especially dedicated to

My loving parents,

My sisters and brother

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

FORMATION, MITIGATION AND ANALYSIS OF 3-MCPD AND GLYCIDYL ESTER DURING DEEP-FAT FRYING OF POTATO CHIPS AND CHICKEN BREAST MEAT USING RBD PALM OLEIN

By

WONG YU HUA

September 2016

Chair: Tan Chin Ping, PhD

Faculty: Food Science and Technology

3-monochloro-1,2-propanediol (3-MCPD) esters and glycidyl ester (GE) are thermally induced contaminants formed during high-temperature processes, such as deep-fat frying (DFF). In this study, the levels of 3-MCPD esters and GE formed during the frying of carbohydrate-rich and protein-rich foods in different frying systems, the effect of antioxidants, and alternative determination method of 3-MCPD esters were studied.

This study was divided into four parts. First, potato chips (a carbohydrate-rich food) were fried in palm olein under different parameters for 5 days. The applied frying temperatures used were 160 °C and 180 °C, and the concentrations of NaCl were 0%, 1%, 3% and 5%. The formation and changes of 3-MCPD esters and GE levels and the oxidative stability of palm olein during DFF were investigated. A high frying temperature resulted in a high level of 3-MCPD esters but a low level of GE. A long frying duration caused a reduction in 3-MCPD esters and an increase in GE. The addition of NaCl to the frying system significantly ($p < 0.05$) increased the level of 3-MCPD esters, but no significant difference ($p > 0.05$) was observed for the GE content. The frying oils and the oils extracted from the potato chips showed similar results. The oil qualities were within the safety limit after 5 days of frying.

Second, chicken breast meats (CBM, a protein-rich food) were fried in palm olein under the same frying conditions mentioned earlier. In general, the result showed similar trends to the frying of carbohydrate-rich food. However, the levels of 3-MCPD esters and GE were higher than those of the potato chips. This is because CBM contains transition metals, such as iron that can accumulate in frying oils, which can further enhance the degradation rate of the oils.

Third, the effect of synthetic (BHA, BHT, and TBHQ) and natural antioxidants (oleoresin rosemary, sage extract) on the oxidative stability and the levels of 3-MCPD esters and GE in palm olein was studied during DFF. The frying systems with added TBHQ and oleoresin rosemary had levels of 3-MCPD esters and GE that were significantly ($p < 0.05$) lower than those of other frying systems. In order of the inhibition ability decrease were TBHQ ≈ oleoresin rosemary > sage extract ≈ BHA ≈ BHT.

Finally, an alternative technique for the estimation of 3-MCPD esters in palm olein using a combined FTIR-chemometric analysis was successfully developed. The results obtained by using FTIR were consistent with the indirect determination method of GC-MS. Chemometric analysis was applied to correlate the content of 3-MCPD esters with the FTIR spectrum data. A partial least squares (PLS) model was able to predict the concentrations of 3-MCPD esters at a 95% confidence level with R^2 values above 0.90. In conclusion, this research can serve as a reference for the effect of frying on the levels of 3-MCPD esters and GEs, the ability of antioxidants in reducing 3-MCPD esters and GE in frying oil and the possibility of applying FTIR-chemometrics in 3-MCPD ester determination.

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

PEMBENTUKAN, MITIGASI DAN ANALISIS 3-MCPD DAN GLISIDIL ESTER SEMASA PROSES PENGGORENGAN JELUK TERHADAP KEREPEK KENTANG DAN DAGING DADA AYAM DENGAN MENGGUNAKAN RBD OLEIN SAWIT

Oleh

WONG YU HUA

September 2016

Pengerusi: Tan Chin Ping, PhD

Fakulti: Sains dan Teknologi Makanan

Kajian telah membuktikan bahawa 3-monokloro-1,2-propanediol (3-MCPD) ester and glisidil ester (GE) adalah bahan kontaminan yang terbentuk dalam proses bersuhu tinggi, seperti proses penggorengan jeluk. Oleh itu, tahap 3-MCPD esters dan GE semasa penggorengan jeluk makanan yang kaya dengan karbohidrat dan protein dalam sistem penggorengan yang berlainan, kesan antioksidan, dan kaedah alternatif untuk menentukan kandungan 3-MCPD esters telah dikaji.

Kajian ini terbahagi kepada empat bahagian. Pertama, kerepek kentang (makanan yang kaya dengan karbohidrat) telah digoreng dalam minyak sawit olein dalam sistem yang berlainan selama 5 hari. Suhu yang digunakan adalah 160 °C and 180 °C dan kepekatan NaCl yang digunakan adalah 0%, 1%, 3% and 5%. Tahap 3-MCPD ester dan GE, serta kestabilan oksidatif minyak sawit olein semasa penggorengan jeluk telah dikaji. Suhu tinggi semasa penggorengan menyebabkan tahap 3-MCPD esters yang tinggi tetapi GE yang rendah. Tempoh penggorengan yang lebih lama menyebabkan pengurangan 3-MCPD ester dan peningkatan GE. Penambahan NaCl dalam sistem penggorengan telah meningkatkan kandungan 3-MCPD esters dengan ketara ($p < 0.05$) tetapi tiada perbezaan ketara ($p > 0.05$) bagi tahap GE. Minyak goreng dan minyak yang diekstrak daripada kerepek kentang juga menunjukkan hasil yang sama. Kualiti minyak didapati masih dalam had keselamatan selepas proses penggorengan selama 5 hari.

Kedua, daging dada ayam (makanan yang kaya dengan protein) telah digoreng dalam minyak sawit olein dengan parameter yang sama seperti yang tertera di atas. Secara amnya, keputusan menunjukan kecenderungan yang serupa dengan makanan yang kaya dengan karbohidrat. Walau bagaimanapun, tahap 3-MCPD esters dan GE adalah lebih

tinggi berbanding dengan kerepek kentang. Ini adalah kerana daging dada ayam mengandungi logam peralihan, seperti besi yang boleh terkumpul dalam minyak goreng, yang dapat meningkatkan kadar degradasi minyak.

Ketiga, kesan antioksidan sintetik (BHA, BHT, TBHQ) dan semula jadi (oleoresin rosemary, ekstrak sage) terhadap kestabilan oksidatif dan tahap 3-MCPD esters dan GE dalam olein sawit semasa proses penggorengan telah dikaji. Sistem penggorengan yang ditambah dengan TBHQ dan oleoresin rosemary mempunyai tahap 3-MCPD ester dan GE yang lebih rendah secara ketara ($p < 0.05$) daripada sistem yang lain. Keberkesanan antioksidan tersebut berkurangan mengikut turutan yang berikut; TBHQ ≈ oleoresin rosemary > sage extract ≈ BHA ≈ BHT.

Akhirnya, satu kaedah alternatif untuk menentukan jumlah 3-MCPD esters dalam minyak sawit olein dengan menggunakan analisis FTIR-kimometrik telah berjaya dihasilkan. Keputusan 3-MCPD ester yang diperolehi daripada FTIR adalah konsisten dengan kaedah tidak langsung yang digunakan, iaitu kaedah GC-MS. Analisis kimometrik telah digunakan untuk menghubungkaitkan kandungan 3-MCPD ester dengan maklumat daripada spektrum FTIR. Model kuasa dua terkecil separa (PLS) dapat meramalkan kandungan 3-MCPD ester dengan tahap keyakinan 95% dan nilai-nilai R^2 melebihi 0.90.

Kesimpulannya, kajian ini boleh digunakan sebagai rujukan untuk kesan penggorengan terhadap tahap 3-MCPD esters dan GE, keupayaan antioksidan dalam mengurangkan 3-MCPD esters dan GE dalam minyak goreng, serta kemungkinan untuk menggunakan FTIR-kimometrik dalam penentuan kandungan 3-MCPD esters.

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest and sincerest appreciation to my supervisor, Prof. Dr. Tan Chin Ping for his valuable advices, patient and encouragement throughout this thesis study. His patience and passion in sharing his knowledge and experience by giving advices and good encouragement lead me to completion of this thesis. This also goes to my co-supervisors, Dr. Nyam Kar Lin, Prof. Dr. Lai Oi Ming, Assoc. Prof. Dr. Faridah Abas, Dr. Halimah binti Muhamad and Dr. Chong Gun Hean for their valuable advices and guidance. This work could not be complete without all of their kind assistance.

I would like to thank lab staffs for their willingness to help and precious advices during my laboratory work. I also express my thankfulness to Biow Ing for her valuable suggestions. A special thank goes to Teck Kim and Yee Lin, who assists me throughout the HPLC analysis. My sincere appreciation also goes to Zahiah for her helping during my sample preparation stage and Mr. Yew from Shimadzu Malaysia for his guidance on FTIR.

Furthermore, I extended my greatest gratitude to my lab mates Phui Yee, Kok Ming, Sky Ng, Tai Boon, Pei Yin, and Hon Weng for giving me helpful opinions and supports during the entire study. I would like to thanks Wei Wei, Shiau Siang, Sin Yen, Sin Yee and Vivian Tan for their encouragements throughout my postgraduate study.

Most of all, I dedicate my deepest love to my beloved dad, mum, sisters and brother for their endless support and motivation during my study.

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:

Tan Chin Ping, PhD
Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Chairman)

Lai Oi Ming, PhD
Professor
Faculty of Biotechnology
Universiti Putra Malaysia
(Member)

Faridah Abas, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

Halimah binti Muhamad, PhD
Analytical and Quality Development Unit
Malaysia Palm Oil Board
(Member)

Nyam Kar Lin, PhD
Associate Professor
Faculty of Food Science with Nutrition
UCSI University
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Wong Yu Hua (GS37289)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Tan Chin Ping, PhD

Signature: _____
Name of Member of Supervisory Committee: Lai Oi Ming, PhD

Signature: _____
Name of Member of Supervisory Committee: Faridah Abas, PhD

Signature: _____
Name of Member of Supervisory Committee: Halimah binti Muhamad, PhD

Signature: _____
Name of Member of Supervisory Committee: Nyam Kar Lin, PhD

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3-MCPD	3-chloropropane-1,2-diol
ALARA	As Low As Reasonably Achievable
ATR	Attenuated total reflection
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
CPO	Crude palm oil
DAG	Diacylglycerol
FFA	Free fatty acids
FFB	Fresh fruit bunches
FTIR	Fourier transform infrared spectrometer
GC	Gas chromatography
GDP	Gross Domestic Product
GE	Glycidyl ester
HPLC	High performance liquid chromatography
IARC	International Agency for Research on Cancer
JECFA	Joint FAO/WHO Expert Committee on Food Additives
MAG	Monoacylglycerol
MS	Mass spectrometry
NaCl	Sodium chloride
PCA	Principal Component Analysis
PKO	Palm kernel oil
PLS	Partial Least Squares
PMTDI	Provisional maximum tolerable daily intake
RBD	Refined, bleached, and deodorized
TAG	Triacylglycerol
TBHQ	Tert-butylhydroquinone
TDI	Tolerable daily intake
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 General Overview

Frying is a common high-temperature food processing method used throughout the world. Simultaneous heat and mass transfer processes are involved in deep fat frying (Debnath, Rastogi, Krishna, & Lokesh, 2009). The quality of the fried food depends on the frying conditions, the type of oils and the food matrix used during the process. After frying, the frying medium (oil) is partially absorbed by the fried food (5 % in frozen French fries, 15–20 % in batter-coated fish and doughnuts, and 35-40 % in potato chips) (Lin, Akoh, & Reynolds, 2001). Therefore, both consumers and researchers are concerned with the quality of frying oils.

Palm oil is the most common edible oil that being used in deep-fat frying. The palm oil industry is one of Malaysia's major agricultural enterprises. Malaysia possesses 2 % of the world's oilseed crop plantations and supplies 10 % of the world's oils and fats (Mekhilef, Siga, & Saidur, 2011). The growth of the palm oil industry is closely related to the increased demand for food and various non-food applications (Castanheira, Acevedo, & Freire, 2014).

3-MCPD esters have been found in foods for many years. More recently, high contents of 3-MCPD esters were also found in refined oils, especially in refined palm oil. It was suggested that the mechanism of formation is related to the heat treatment of the oilseeds during the refining process. Malaysia, as the world's leading palm oil-producing country, recognizes the importance of the problem and is taking steps to monitor refined oils. Much strong evidence has been reported in the scientific literature for the formation of 3-MCPD and glycidyl ester during palm oil refining. It is generally believed that the formation of 3-MCPD and glycidyl ester is due to the exposure of palm oil to high temperatures during the edible oil deodorization step. The formation mechanism of 3-MCPD esters and GE involves the acyloxonium ion as an intermediate, which is produced from partial acylglycerol. Hence, it is worth investigating the effects of synthetic and natural antioxidants on the formation of 3-MCPD esters and GE in frying oils.

The potato (*Solanum tuberosum* L.) is the top 5 most important crop in the world after sugar cane, maize, wheat and rice, with a production of more than 329 million tonnes in 2009 (FAO, 2012). According to Norimah et al. (2008), the chicken is one of the most consumed type of poultry in Malaysia in both urban and rural areas. As frying is the most

common method used in potato and chicken cooking, changes in the oil stability and the formation of hazardous compounds need to be evaluated.

The commonly use method for 3-MCPD esters and GE determination is indirect acid transesterification and derivatization followed by the use of gas chromatography with mass spectrometric detection (GC-MS). It had good repeatability and reproducibility. However, this method has complicated preparation steps and required 16 h incubation. The Fourier transform infrared spectrometer (FTIR) has been used for various food applications to monitor the quality and safety of foods by providing information on their biochemical composition (Ayvaz & Rodriguez-Saona, 2015). This analytical method requires simple or no sample preparation and minimal solvent, and the analysis process is rapid. FTIR spectroscopy is frequently combined with multivariate analysis to make this technology ideal for rapid screening, as well as the identification of various complex compounds.

1.2 Objectives

i. To determine the oxidative stability and levels of 3-chloropropane-1,2-diol (3-MCPD) esters and glycidyl ester (GE) in palm olein during the deep-frying of potato chips.
ii. To determine the oxidative stability and levels of 3-chloropropane-1,2-diol (3-MCPD) esters and glycidyl ester (GE) in palm olein during the deep-frying of chicken breast meat.
iii. To determine the effects of synthetic and natural antioxidants on the oxidative stability and levels of 3-chloropropane-1,2-diol (3-MCPD) esters and glycidyl ester (GE) in palm olein during deep-frying of potato chips.
iv. To develop an alternative technique for the estimation of the 3-monochloropropane-1,2-diol (MCPD) ester content in palm olein by using FTIR coupled with chemometric analysis.

BIBLIOGRAPHY

Abraham, K., Appel, K. E., Berger-Preiss, E., Apel, E., Gerling, S., Mielke, H., . . . Lampen, A. (2013). Relative oral bioavailability of 3-MCPD from 3-MCPD fatty acid esters in rats. *Archives of toxicology, 87*(4), 649-659.

Adeyemi, K., & Olorunsanya, A. (2012). Comparative analysis of phenolic composition and antioxidant effect of seed coat extracts of four cowpea (Vigna unguiculata) varieties on broiler meat. *Iranian Journal of Applied Animal Science, 2*(4), 343-349.

Akoh, C. C., & Min, D. B. (2008). *Food lipids: chemistry, nutrition, and biotechnology*: CRC press.

Al-Degs, Y. S., Al-Ghouti, M., & Salem, N. (2011). Determination of frying quality of vegetable oils used for preparing falafel using infrared spectroscopy and multivariate calibration. *Food Analytical Methods, 4*(4), 540-549.

Andres, S., Appel, K. E., & Lampen, A. (2013). Toxicology, occurrence and risk characterisation of the chloropropanols in food: 2-monochloro-1,3-propanediol, 1,3-dichloro-2-propanol and 2,3-dichloro-1-propanol. *Food Chem Toxicol, 58*, 467-478. doi: 10.1016/j.fct.2013.05.024

Aniolowska, M. A., & Kita, A. M. (2016). The effect of raw materials on thermo-oxidative stability and glycidyl ester content of palm oil during frying. *J Sci Food Agric, 96*(6), 2257-2264. doi: 10.1002/jsfa.7345

Arab-Tehrany, E., Jacquot, M., Gaiani, C., Imran, M., Desobry, S., & Linder, M. (2012). Beneficial effects and oxidative stability of omega-3 long-chain polyunsaturated fatty acids. *Trends in food science & technology, 25*(1), 24-33. doi: http://dx.doi.org/10.1016/j.tifs.2011.12.002

Artz, W. E., Osidacz, P. C., & Coscione, A. R. (2005). Iron accumulation in oil during the deep-fat frying of meat. *Journal of the American Oil Chemists' Society, 82*(4), 249-254.

Aruoma, O. I., & Cuppett, S. L. (1997). *Antioxidant methodology: in vivo and in vitro concepts*: The American Oil Chemists Society.

Ayvaz, H., & Rodriguez-Saona, L. E. (2015). Application of handheld and portable spectrometers for screening acrylamide content in commercial potato chips. *Food Chem, 174*, 154-162. doi: 10.1016/j.foodchem.2014.11.001

Badriah, A. (2012). Effect of frying oils on quality characteristics of frozen chicken patties incorporated with honey. *African Journal of Biotechnology, 11*(12). doi: 10.5897/ajb11.3389

Baer, I., de la Calle, B., & Taylor, P. (2010). 3-MCPD in food other than soy sauce or hydrolysed vegetable protein (HVP). *Analytical and bioanalytical chemistry, 396*(1), 443-456.

Bakhiya, N., Abraham, K., Gurtler, R., Appel, K. E., & Lampen, A. (2011). Toxicological assessment of 3-chloropropane-1,2-diol and glycidol fatty acid esters in food. *Mol Nutr Food Res, 55*(4), 509-521. doi: 10.1002/mnfr.201000550

Bansal, G., Zhou, W., Barlow, P. J., Lo, H.-L., & Neo, F.-L. (2010). Performance of palm olein in repeated deep frying and controlled heating processes. *Food Chemistry, 121*(2), 338-347. doi: 10.1016/j.foodchem.2009.12.034

Barocelli, E., Corradi, A., Mutti, A., & Petronini, P. (2011). Comparison between 3-MCPD and its palmitic esters in a 90-day toxicological study. *SCIENTIFIC REPORT submitted to EFSA. CFP/EFSA/CONTAM/2009/01. Accepted for publication on, 22*.

Bertoli, C., Cauville, F., & Schoonman, A. J. H. (2014). Deodorized edible oil or fat with low levels of bound MCPD and process of making by carboxymethyl cellulose and/or resin purification: Google Patents.

Budilarto, E. S., & Kamal-Eldin, A. (2015). The supramolecular chemistry of lipid oxidation and antioxidation in bulk oils. *Eur J Lipid Sci Technol, 117*(8), 1095-1137. doi: 10.1002/ejlt.201400200

Bunger, A., Moyano, P., & Rioseco, V. (2003). NaCl soaking treatment for improving the quality of french-fried potatoes. *Food Research International, 36*(2), 161-166. doi: http://dx.doi.org/10.1016/S0963-9969(02)00131-X

Bursal, E., & Gülçin, İ. (2011). Polyphenol contents and in vitro antioxidant activities of lyophilised aqueous extract of kiwifruit (Actinidia deliciosa). *Food Research International, 44*(5), 1482-1489.

Castanheira, É. G., Acevedo, H., & Freire, F. (2014). Greenhouse gas intensity of palm oil produced in Colombia addressing alternative land use change and fertilization scenarios. *Applied Energy, 114*, 958-967.

Chang, I., & Watts, B. M. (1950). SOME EFFECTS OF SALT AND MOISTURE ON RANCIDITY IN FATS 1. *J Food Sci, 15*(4), 313-321.

Chaturvedi, S., Joshi, A., & Dubey, B. (2011). Pharmacognostical, phytochemical and cardioprotective activity of Tamarinds indica Linn. bark. *International Journal of Pharmaceutical Sciences and Research, 2*(11), 3019.

Che Man, Y. B., & Tan, C. P. (1999). Effects of natural and synthetic antioxidants on changes in refined, bleached, and deodorized palm olein during deep-fat frying of potato chips. *Journal of the American Oil Chemists' Society, 76*(3), 331-339. doi: 10.1007/s11746-999-0240-y

Choe, E., Choe, E., & Min, D. B. (2007). Chemistry of Deep-Fat Frying Oils. *J Food Sci, 72*(5), R77-R86. doi: 10.1111/j.1750-3841.2007.00352.x

Coates, J. (2000). Interpretation of infrared spectra, a practical approach. *Encyclopedia of analytical chemistry*.

Craft, B. D., Nagy, K., Sandoz, L., & Destaillats, F. (2012). Factors impacting the formation of monochloropropanediol (MCPD) fatty acid diesters during palm (Elaeis guineensis) oil production. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 29*(3), 354-361. doi: 10.1080/19440049.2011.639034

Craft, B. D., Nagy, K., Seefelder, W., Dubois, M., & Destaillats, F. (2012). Glycidyl esters in refined palm (Elaeis guineensis) oil and related fractions. Part II: Practical recommendations for effective mitigation. *Food Chemistry, 132*(1), 73-79. doi: 10.1016/j.foodchem.2011.10.034

Crews, C., Chiodini, A., Granvogl, M., Hamlet, C., Hrncirik, K., Kuhlmann, J., . . . Seefelder, W. (2013). Analytical approaches for MCPD esters and glycidyl esters in food and biological samples: a review and future perspectives. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 30*(1), 11-45. doi: 10.1080/19440049.2012.720385

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

Debnath, S., Rastogi, N., Krishna, A. G., & Lokesh, B. (2009). Oil partitioning between surface and structure of deep-fat fried potato slices: A kinetic study. *LWT-Food Science and Technology, 42*(6), 1054-1058.

Destaillats, F., Craft, B. D., Dubois, M., & Nagy, K. (2012). Glycidyl esters in refined palm (Elaeis guineensis) oil and related fractions. Part I: Formation mechanism. *Food Chemistry, 131*(4), 1391-1398. doi: 10.1016/j.foodchem.2011.10.006

Divinova, V., Svejkovska, B., Dolezal, M., & Velisek, J. (2004). Determination of free and bound 3-chloropropane-1, 2-diol by gas chromatography with mass spectrometric detection using deuterated 3-chloropropane-1, 2-diol as internal standard. *Czech Journal of Food Sciences, 22*(5), 182-189.

Dubois, M., Tarres, A., Goldmann, T., Empl, A. M., Donaubauer, A., & Seefelder, W. (2012). Comparison of indirect and direct quantification of esters of monochloropropanediol in vegetable oil. *J Chromatogr A, 1236*, 189-201. doi: 10.1016/j.chroma.2012.03.009

Enríquez-Fernández, B. E., Álvarez de la Cadena y Yañez, L., & 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. doi: 10.1111/j.1365-2621.2011.02627.x

Esposto, S., Taticchi, A., Di Maio, I., Urbani, S., Veneziani, G., Selvaggini, R., . . . Servili, M. (2015). Effect of an olive phenolic extract on the quality of vegetable oils during frying. *Food Chemistry, 176*, 184-192.

FAO. (2012). FAOSTAT crop production. Retrieved 19 April, 2016, from http://faostat.fao.org

Food and Agricultural Association, F. (2013). Palm oil processing. Retrieved 19 April, 2016, from http://www.fao.org/docrep/005/y4355e/y4355e04.htm

Guerrero-Legarreta, I. (2010). *Handbook of poultry science and technology: Volume 1: Primary processing*: John Wiley & Sons, Inc.

Gurdeniz, G., & Ozen, B. (2009). Detection of adulteration of extra-virgin olive oil by chemometric analysis of mid-infrared spectral data. *Food Chemistry, 116*(2), 519-525.

Gurdeniz, G., Tokatli, F., & Ozen, B. (2007). Differentiation of mixtures of monovarietal olive oils by mid-infrared spectroscopy and chemometrics. *European Journal of Lipid Science and Technology, 109*(12), 1194-1202. doi: 10.1002/ejlt.200700087

Hamid, A., Aiyelaagbe, O., Usman, L., Ameen, O., & Lawal, A. (2010). Antioxidants: Its medicinal and pharmacological applications. *Afr J Pure Appl Chem, 4*(8), 142-151.

Hamlet, C., & Sadd, P. (2004). Chloropropanols and their esters in cereal products. *Czech Journal of Food Sciences, 22*, 259-262.

Hamlet, C. G., Asuncion, L., Velíšek, J., Doležal, M., Zelinková, Z., & Crews, C. (2011). Formation and occurrence of esters of 3-chloropropane-1,2-diol (3-CPD) in foods: What we know and what we assume. *European Journal of Lipid Science and Technology, 113*(3), 279-303. doi: 10.1002/ejlt.201000480

Haris, P. I., & Chapman, D. (1992). Does Fourier-transform infrared spectroscopy provide useful information on protein structures? *Trends in biochemical sciences, 17*(9), 328-333.

Hori, K., Koriyama, N., Omori, H., Kuriyama, M., Arishima, T., & Tsumura, K. (2012). Simultaneous determination of 3-MCPD fatty acid esters and glycidol fatty acid esters in edible oils using liquid chromatography time-of-flight mass spectrometry. *LWT-Food Science and Technology, 48*(2), 204-208.

Houhoula, D. P., Oreopoulou, V., & Tzia, C. (2003). The effect of process time and temperature on the accumulation of polar compounds in cottonseed oil during deep-fat frying. *J Sci Food Agric, 83*(4), 314-319.

Hwang, M., Yoon, E., Kim, J., Jang, D. D., & Yoo, T. M. (2009). Toxicity value for 3-monochloropropane-1, 2-diol using a benchmark dose methodology. *Regulatory Toxicology and Pharmacology, 53*(2), 102-106.

Izbaim, B., Faiz, B., Moudden, A., & Hammine, A. (2009). Use of ultrasonic for the quality assessment of frying oil. *J Int Signal Syst Control Eng Appl, 2*(2), 35-39.

Jędrkiewicz, R., Kupska, M., Głowacz, A., Gromadzka, J., & Namieśnik, J. (2015). 3-MCPD: A Worldwide Problem of Food Chemistry. *Critical Reviews in Food Science and Nutrition*, 00-00. doi: 10.1080/10408398.2013.829414

Joffre, F., Griffon, H., Soulet, B., & Lacoste, F. (2003). *3-MCPD esters in edible oils: analytical aspects.* Paper presented at the Graz: Euro Fed Lipid Congress, 2009 [2012-9-10]. http://www, aocs. org/files/ResourcesPDF/EFL% 203MCPD% 20octO9. pdf.

Kassama, L., & Ngadi, M. (2004). Pore development in chicken meat during deep-fat frying. *LWT-Food Science and Technology, 37*(8), 841-847.

Khoramnia, A., Ebrahimpour, A., Ghanbari, R., & Ajdari, Z. (2013). Improvement of Medium Chain Fatty Acid Content and Antimicrobial Activity of Coconut Oil via Solid-State Fermentation Using a Malaysian Geotrichum candidum. *Journal of investigative dermatology, 2013*(2), 1-9. doi: 10.1155/2013/954542

Kok, S., Ong-Abdullah, M., Ee, G. C., & Namasivayam, P. (2011). Comparison of nutrient composition in kernel of tenera and clonal materials of oil palm (Elaeis guineensis Jacq.). *Food Chemistry, 129*(4), 1343-1347. doi: 10.1016/j.foodchem.2011.05.023

Kuhlmann, J. (2011). Determination of bound 2, 3-epoxy-1-propanol (glycidol) and bound monochloropropanediol (MCPD) in refined oils. *European Journal of Lipid Science and Technology, 113*(3), 335-344.

Küsters, M., Bimber, U., Ossenbrüggen, A., Reeser, S., Gallitzendörfer, R., & Gerhartz, M. (2010). Rapid and simple micromethod for the simultaneous determination of 3-MCPD and 3-MCPD esters in different foodstuffs. *J Agric Food Chem, 58*(11), 6570-6577.

Lai, O.-M., Tan, C.-P., & Akoh, C. C. (2012). Palm Oil - Production, Processing, Characterization, and Uses: AOCS Press.

Lamaming, J., Hashim, R., Sulaiman, O., Sugimoto, T., Sato, M., & Hiziroglu, S. (2014). Measurement of some properties of binderless particleboards made from young and old oil palm trunks. *Measurement, 47*, 813-819.

Li, C., Jia, H., Wang, Y., Shen, M., Nie, S., & Xie, M. (2015). Determination of 3-Monochloropropane-1, 2-Diol Esters in Edible Oil—Method Validation and Estimation of Measurement Uncertainty. *Food Analytical Methods*, 1-11.

Lodish, H., Berk, A., & Zipursky, S. (2000). Molecular cell biology 4th edition.

Maisuthisakul, P., Suttajit, M., & Pongsawatmanit, R. (2007). Assessment of phenolic content and free radical-scavenging capacity of some Thai indigenous plants. *Food Chemistry, 100*(4), 1409-1418.

Márquez-Ruiz, G., Ruiz-Méndez, M. V., & Velasco, J. (2014). Antioxidants in frying: Analysis and evaluation of efficacy. *European Journal of Lipid Science and Technology, 116*(11), 1441-1450. doi: 10.1002/ejlt.201400063

Maskan, M., & 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. doi: 10.1007/s00217-003-0794-0

Maskan, M., & İnanç, T. (2014). Effect of carvacrol on the oxidative stability of palm oil during frying. *Grasas y Aceites, 65*(4), e042. doi: 10.3989/gya.0350141

Masukawa, Y., Shiro, H., Nakamura, S., Kondo, N., Jin, N., Suzuki, N., . . . Kudo, N. (2010). A new analytical method for the quantification of glycidol fatty acid esters in edible oils. *Journal of oleo science, 59*(2), 81-88.

Matthäus, B. (2007). Use of palm oil for frying in comparison with other high-stability oils. *European Journal of Lipid Science and Technology, 109*(4), 400-409. doi: 10.1002/ejlt.200600294

Matthäus, B. (2011). 3-MCPD and glycidyl fatty acid esters: What is the knowledge today? *European Journal of Lipid Science and Technology, 113*(3), 277-278. doi: 10.1002/ejlt.201100025

Matthäus, B., Pudel, F., Fehling, P., Vosmann, K., & Freudenstein, A. (2011). Strategies for the reduction of 3-MCPD esters and related compounds in vegetable oils. *European Journal of Lipid Science and Technology, 113*(3), 380-386. doi: 10.1002/ejlt.201000300

McSavage, J., & Trevisan, S. (2001). The use and abuse of frying oil. *Food Service Technology, 1*(2), 85-92.

Mekhilef, S., Siga, S., & Saidur, R. (2011). A review on palm oil biodiesel as a source of renewable fuel. *Renewable and Sustainable Energy Reviews, 15*(4), 1937-1949.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in food science & technology, 14*(9), 364-373.

Mir-Bel, J., Oria, R., & Salvador, M. L. (2009). Influence of the vacuum break conditions on oil uptake during potato post-frying cooling. *Journal of Food Engineering, 95*(3), 416-422.

Moravcova, E., Vaclavik, L., Lacina, O., Hrbek, V., Riddellova, K., & Hajslova, J. (2012). Novel approaches to analysis of 3-chloropropane-1, 2-diol esters in vegetable oils. *Analytical and bioanalytical chemistry, 402*(9), 2871-2883.

MPOB, M. P. O. B. (2007). About palm oil. Retrieved 19 April, 2016, from http://www.palmoilworld.org/about_palmoil.html

MPOB, M. P. O. B. (2012). Oil palm planted area by category. Retrieved 19 April, 2016, from http://www.palmoilworld.org/about_malaysian-industry.html

MPOC, M. P. O. C. (2013). The Oil Palm Tree. Retrieved 19 April, 2016, from http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx

Murniece, I., Karklina, D., Galoburda, R., Santare, D., Skrabule, I., & Costa, H. S. (2011). Nutritional composition of freshly harvested and stored Latvian potato (Solanum tuberosum L.) varieties depending on traditional cooking methods. *Journal of food composition and Analysis, 24*(4), 699-710.

Nadhari, W. N. A. W., Hashim, R., Sulaiman, O., & Jumhuri, N. (2014). Drying kinetics of oil palm trunk waste in control atmosphere and open air convection drying. *International Journal of Heat and Mass Transfer, 68*, 14-20.

Naz, S., Siddiqi, R., & Asad Sayeed, S. (2008). Effect of flavonoids on the oxidative stability of corn oil during deep frying. *International Journal of Food Science & Technology, 43*(10), 1850-1854. doi: 10.1111/j.1365-2621.2008.01731.x

Naz, S., Siddiqi, R., Sheikh, H., & Sayeed, S. A. (2005). Deterioration of olive, corn and soybean oils due to air, light, heat and deep-frying. *Food Research International, 38*(2), 127-134.

Nigam, P. S., & Pandey, A. (2009). *Biotechnology for agro-industrial residues utilisation*: Springer.

Norimah, A. K., Safiah, M. Y., Jamal Khair, H., Din, M., Siti, H., Zuhaida, H., . . . Siti, N. (2008). Food consumption patterns: findings from the Malaysian Adult Nutrition Survey (MANS). *Malaysian Journal of Nutrition, 14*(1), 25-39.

Norppa, H., Hemminki, K., Sorsa, M., & Vainio, H. (1981). Effect of monosubstituted epoxides on chromosome aberrations and SCE in cultured human lymphocytes. *Mutation Research Letters, 91*(3), 243-250.

NTP, N. T. P. (1990). NTP Toxicology and Carcinogenesis Studies of Glycidol (CAS No. 556-52-5) In F344/N Rats and B6C3F1 Mice (Gavage Studies). *National Toxicology Program technical report series, 374*, 1.

Olorunsanya, O., Olorunsanya, E., Akanbi, A., & RMO, K. (2009). Antioxidant properties of rice husk extract in raw and cooked pork patties. *J. Applied Agricultural research, 1*, 143-14718.

Paradkar, M. M., Sivakesava, S., & Irudayaraj, J. (2003). Discrimination and classification of adulterants in maple syrup with the use of infrared spectroscopic techniques. *J Sci Food Agric, 83*(7), 714-721.

Pedreschi, F. (2012). Frying of Potatoes: Physical, Chemical, and Microstructural Changes. *Drying Technology, 30*(7), 707-725. doi: 10.1080/07373937.2012.663845

Poiana, M. A. (2012). Enhancing oxidative stability of sunflower oil during convective and microwave heating using grape seed extract. *Int J Mol Sci, 13*(7), 9240-9259. doi: 10.3390/ijms13079240

Prior, R. L., Wu, X., & Schaich, K. (2005). Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. *J Agric Food Chem, 53*(10), 4290-4302.

Pudel, F., Benecke, P., Vosmann, K., & Matthäus, B. (2016). 3-MCPD- and glycidyl esters can be mitigated in vegetable oils by use of short path distillation. *European Journal of Lipid Science and Technology, 118*(3), 396-405. doi: 10.1002/ejlt.201500095

Rahn, A. K. K., & Yaylayan, V. A. (2011). What do we know about the molecular mechanism of 3-MCPD ester formation? *European Journal of Lipid Science and Technology, 113*(3), 323-329. doi: 10.1002/ejlt.201000310

Rakesh, S. U., Patil, P. R., & Mane, S. R. (2010). Use of natural antioxidants to scavenge free radicals: a major cause of diseases. *Int. J. Pharm. Tech. Res, 2*, 1074-1081.

Ramli, M. R., Siew, W. L., Ibrahim, N. A., Hussein, R., Kuntom, A., Abd. Razak, R. A., & Nesaretnam, K. (2011). Effects of Degumming and Bleaching on 3-MCPD Esters Formation During Physical Refining. *Journal of the American Oil Chemists' Society, 88*(11), 1839-1844. doi: 10.1007/s11746-011-1858-0

Réblová, Z., Tichovská, D., & Doležal, M. (2009). Heating of plant oils–fatty acid reactions versus tocopherols degradation. *Czech Journal of Food Sciences (Special Issue), 27*, S185-S187.

Rohman, A., & Man, Y. B. C. (2010). Fourier transform infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. *Food Research International, 43*(3), 886-892. doi: 10.1016/j.foodres.2009.12.006

Romero, A., Cuesta, C., & Sánchez-Muniz, F. J. (1998). Effect of oil replenishment during deep-fat frying of frozen foods in sunflower oil and high-oleic acid sunflower oil. *Journal of the American Oil Chemists' Society, 75*(2), 161-167.

Rossell, J. B. (2001). *Frying: improving quality*. Cambridge, England;Boca Raton, Fla;: CRC Press.

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

Sanhueza, J., Nieto, S., & Valenzuela, A. (2000). Thermal stability of some commercial synthetic antioxidants. *Journal of the American Oil Chemists' Society, 77*(9), 933-936.

Schrenk, D. (2012). *Chemical contaminants and residues in food*: Elsevier.

Seefelder, W., Varga, N., Studer, A., Williamson, G., Scanlan, F., & Stadler, R. (2008). Esters of 3-chloro-1, 2-propanediol (3-MCPD) in vegetable oils: significance in the formation of 3-MCPD. *Food Addit Contam, 25*(4), 391-400.

Serjouie, A., Tan, C. P., Mirhossein, H., & Che Man, Y. B. (2010). Effect of Vegetable-Based Oil Blends on Physicochemical Properties of Oils During Deep-Fat Frying. *American journal of food technology, 5*(5), 310-323. doi: 10.3923/ajft.2010.310.323

Shahidi, F. (2005). *Bailey's Industrial Oil and Fat Products, 6 Volume Set* (Vol. 4): Chapter.

Shalaby, E., & Shanab, S. (2013). Antioxidant compounds, assays of determination and mode of action. *African Journal of Pharmacy and Pharmacology, 7*(10), 528-539.

Shi, L.-E., Zhang, Z.-L., Xing, L.-Y., Yang, D.-D., Guo, X.-F., & Tang, Z.-X. (2011). Antioxidants extraction by supercritical CO2. *Journal of Medicinal Plants Research, 5*(3), 300-308.

Shimizu, M., Vosmann, K., & Matthäus, B. (2012). Generation of 3-monochloro-1,2-propanediol and related materials from tri-, di-, and monoolein at deodorization temperature. *European Journal of Lipid Science and Technology, 114*(11), 1268-1273. doi: 10.1002/ejlt.201200078

Shimizu, M., Weitkamp, P., Vosmann, K., & Matthäus, B. (2013). Influence of chloride and glycidyl-ester on the generation of 3-MCPD- and glycidyl-esters. *European Journal of Lipid Science and Technology, 115*(7), 735-739. doi: 10.1002/ejlt.201200310

Smith, B. C. (2011). *Fundamentals of Fourier transform infrared spectroscopy*: CRC press.

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

Svejkovska, B., Dolezal, M., & Velisek, J. (2006). Formation and decomposition of 3-chloropropane-1, 2-diol esters in models simulating processed foods. *Czech Journal of Food Sciences, 24*(4), 172.

Tabee, E., Azadmard-Damirchi, S., Jägerstad, M., & Dutta, P. C. (2008). Lipids and phytosterol oxidation in commercial French fries commonly consumed in Sweden. *Journal of food composition and Analysis, 21*(2), 169-177.

Velisek, J., Calta, P., Crews, C., Hasnip, S., & Marek, D. (2003). 3-Chloropropane-1,2-diol in Models Simulating Processed Foods: Precursors and Agents Causing its Decomposition. *Czech J. Food Sci., 21*(5).

Velisek, J., Davidek, J., Kubelka, V., Bartosova, J., Tuckova, A., Hajslova, J., & Janicek, G. (1979). Formation of volatile chlorohydrins from glycerol (triacetin, tributyrin) and hydrochloric acid. *Lebensmittel-Wissenschaft+ Technologie. Food science+ technology*.

Vijayalakshmi, G., Adinarayana, M., & Jayaprakash Rao, P. (2012). Kinetics and mechanism of regeneration of β-carotene from tert-butoxyl radical induced β-carotene radical cation by αtocopherol: A synergistic interaction. *Journal of Chemistry and Pharmaceutical Research, 4*(7), 3574-3582.

Weißhaar, R., & Perz, R. (2010). Fatty acid esters of glycidol in refined fats and oils. *European Journal of Lipid Science and Technology, 112*(2), 158-165. doi: 10.1002/ejlt.200900137

Yamazaki, K., Ogiso, M., Isagawa, S., Urushiyama, T., Ukena, T., & Kibune, N. (2013). A new, direct analytical method using LC-MS/MS for fatty acid esters of 3-chloro-1, 2-propanediol (3-MCPD esters) in edible oils. *Food Additives & Contaminants: Part A, 30*(1), 52-68.

Yanai, N., Shiotani, S., Hagiwara, S., Nabetani, H., & Nakajima, M. (2008). Antioxidant combination inhibits reactive oxygen species mediated damage. *Bioscience, biotechnology, and biochemistry, 72*(12), 3100-3106.

Zelinková, Z., Svejkovská, B., Velíšek, J., & Doležal, M. (2006). Fatty acid esters of 3-chloropropane-1, 2-diol in edible oils. *Food Addit Contam, 23*(12), 1290-1298.

Zhang, Q., Saleh, A. S., Chen, J., & Shen, Q. (2012). Chemical alterations taken place during deep-fat frying based on certain reaction products: a review. *Chem Phys Lipids, 165*(6), 662-681. doi: 10.1016/j.chemphyslip.2012.07.002

Zhang, X., Gao, B., Qin, F., Shi, H., Jiang, Y., Xu, X., & Yu, L. L. (2013). Free radical mediated formation of 3-monochloropropanediol (3-MCPD) fatty acid diesters. *J Agric Food Chem, 61*(10), 2548-2555. doi: 10.1021/jf305252q

Ziaiifar, A. M., Courtois, F., & Trystram, G. (2010). Porosity development and its effect on oil uptake during frying process. *Journal of food process engineering, 33*(2), 191-212.