UNIVERSITI PUTRA MALAYSIA

A NEW REFINING APPROACH FOR PRODUCTION OF REFINED PALM OIL WITH REDUCED CONTENTS OF 3-MONOCHLOROPROPANE-1,2-DIOL ESTERS AND GLYCIDYL ESTERS

HEW KHAI SHIN

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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 Master of Science

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Dedicating this dissertation to my dearest little brother, may you only walk on flower path in your next life. I love you and miss you forever.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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November 2019

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

With the recent launch of a new legislation on the maximum limit of glycidyl esters (GE) in food products, the maximum limit of 3-monochloropropane-1,2-diol esters (3-MCPDE) in oil is expected to be introduced soon. Therefore, devising strategies to mitigate these carcinogenic esters in refined palm oil is of urgent priority now. This research aimed to firstly, revise the pre-treatment steps in palm oil refining (degumming and bleaching) in order to minimize the formation of 3-MCPDE and GE in refined, bleached, deodorized palm oil (RBDPO); and secondly, to develop and optimize a new refining approach for the production of high quality RBDPO with reduced 3-MCPDE and GE contents. For the first objective, water degumming that requires no centrifugation and decanting was incorporated into the refining process (1.0% water (w/w), 90 °C, 10 min). This modification successfully reduced 23% of 3-MCPDE and 13% of GE in RBDPO significantly ($p < 0.05$). Next, six types of bleaching earth (BE) were dosed at 0.5%, 1.0% and 1.5% (w/w) to evaluate their effects on the esters contents in RBDPO. Results showed that high dosage of BE did not promote the maximum reduction of esters contents in oil. Instead, each type of BE had their own optimal dosage to work against the esters. Pore structure, which is a typical performance indicator of BE, was unable to explain the varying capabilities of BE to control the esters formation. The surface acidity of BE was a more accurate performance marker instead. Acid-activated BE (AABE) was found to have greater esters reduction effect as compared to natural BE. AABE of low surface acidity (pH $\simeq$ 5) was found to be excellent for the production of RBDPO with the least amounts of 3-MCPDE and GE, while AABE of high surface acidity (pH $\simeq$ 3) was found to greatly promote the formations of 3-MCPDE and GE.

The modified refining method was optimized by using response surface methodology to produce RBDPO with minimum 3-MCPDE, GE and FFA contents and lowest oil color, with water dosage (0.5-1.5%), acid dosage (0.04-0.08%), pre-treatment

temperature (60-90 °C), deodorization temperature (240-260 °C) and duration (80-120 min) as the independent variables. Among all, deodorization temperature was the most critical factor that significantly affected all responses ($p < 0.05$). High pre-treatment temperature was found to exert considerable impact on the formation of both esters ($p < 0.05$), by which it significantly promoted the formation of 3-MCPDE and simultaneously decreased the formation of GE at its high level. Other than this, the interaction effect between acid and water dosage strongly impacted 3-MCPDE content too. An optimum and verified model was obtained, which resulted in 78% reduction for 3-MCPDE and 53% of reduction for GE, as compared to RBDPO that was refined conventionally. The efficiency of the new refining method was assessed on four grades of crude palm oil as the third objective of this study. Similar esters mitigation effect was observed across all grades of oil, thus confirming the ester mitigation efficiency of the new refining approach.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PROSES PENULENAN MINYAK SAWIT BAHARU UNTUK PENGHASILAN MINYAK SAWIT TERTAPIS DENGAN KANDUNGAN 3-MONOCHLOROPROPANE-1,2-DIOL ESTERS DAN GLYCIDYL ESTERS YANG RENDAH

Oleh

HEW KHAI SHIN

November 2019

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

Dengan pelaksanaan undang-undang baharu mengenai kandungan maksimum *glycidyl esters* (GE) dalam makanan, undang-undang untuk had maksimum kandungan *3-monochloropropane-1,2-diol esters* (3-MCPDE) dalam minyak dijangka akan diperkenalkan dalam masa terdekat. Oleh yang demikian, strategi-strategi untuk mengurangkan kompaun karsinogenik tersebut perlu diutamakan. Matlamat pertama penyelidikan ini adalah untuk mengkaji semula langkah-langkah pra-rawatan dalam proses penulenan minyak sawit, iaitu proses nyah gam dan proses pelunturan, untuk mengurangkan pembentukan 3-MCPDE dan GE dalam minyak sawit tertapis (RBDPO). Seterusnya, proses penulenan minyak sawit baharu akan dioptimumkan supaya RBDPO yang berkualiti tinggi dengan kandungan 3-MCPDE dan GE yang minimum boleh dihasilkan. Bagi matlamat pertama, kaedah nyah gam air yang tidak memerlukan langkah pengemparan atau pemisahan (1.0% air (w/w), 90 °C, 10 min) telah disertakan dalam proses penulenan. Modifikasi tersebut telah berjaya mengurangkan 23% 3-MCPDE dan 13% GE dalam RBDPO secara ketara ($p < 0.05$). Seterusnya, enam jenis peluntur bumi (BE) telah digunakan pada 0.5%, 1.0% and 1.5% (w/w) untuk menilai kesan-kesan mereka terhadap kandungan ester dalam RBDPO. Hasil kajian menunjukkan bahawa dos BE yang tinggi tidak membawa kepada pengurangan kandungan ester yang maksimum. Akan tetapi, setiap jenis BE berfungsi pada dos optimum masing-masing. Struktur pori yang sering dianggap sebagai petunjuk prestasi BE yang tipikal gagal menjelaskan perbezaan prestasi BE dalam pengawalan pembentukan ester. Sebaliknya, keasidan permukaan BE telah dikenalpasti sebagai petunjuk prestasi BE yang lebih tepat. BE yang diaktifkan dengan asid (AABE) didapati mempunyai kesan pengurangan kandungan ester yang lebih baik berbanding dengan BE semulajadi. AABE dengan keasidan permukaan yang rendah (pH $\simeq$ 5) didapati sangat berkesan untuk penghasilan RBDPO dengan kandungan 3-MCPDE dan GE yang terendah, manakala AABE dengan keasidan permukaan yang tinggi (pH $\simeq$ 3) didapati menggalakkan pembentukan 3-MCPDE dan GE.

Proses penulenan yang telah diubahsuai kemudian dioptimumkan dengan *response surface methodology* (RSM) untuk menghasilkan RBDPO yang mengandungi 3-MCPDE, GE dan FFA yang minimum serta warna minyak yang terang, dengan dos air (0.5-1.5%), dos asid (0.04-0.08%), suhu pra-rawatan (60-90 °C), suhu proses penyahbauan (240-260 °C) dan masa proses penyahbauan (80-120 min) sebagai pembolehubah yang dimanipulasi. Suhu proses penyahbauan merupakan faktor paling kritikal yang mempengaruhi semua pembolehubah bergerak balas secara ketara ($p < 0.05$). Suhu peringkat pra-rawatan yang tinggi turut membawa impak yang ketara ke atas kandungan kedua-dua ester ($p < 0.05$), di mana ianya didapati menggalakkan pembentukan 3-MCPDE dengan ketara dan pada masa yang sama, menurunkan kandungan GE pada suhu yang tinggi. Selain itu, interaksi antara dos air dan dos asid turut memberi kesan yang agak besar ke atas kandungan 3-MCPDE. Model yang optimum dan sah turut diperolehi, dengan kadar pengurangan sebanyak 78% bagi kandungan 3-MCPDE dan 53% bagi kandungan GE berbanding dengan RBDPO yang diproses secara konvensional. Kecekapan proses penulenan baharu ini turut dinilai dengan menggunakan minyak sawit mentah yang berlainan gred sebagai matlamat yang ketiga. Kesan pengurangan yang serupa telah didapati bagi kesemua gred minyak tersebut. Dengan ini, kecekapan dan keberkesanan proses penulenan minyak baharu ini telah dibuktikan.

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I certify that a Thesis Examination Committee has met on 27th November 2019 to conduct the final examination of Hew Khai Shin on her thesis entitled "A New Refining Approach for the Production of Refined Palm Oil with Reduced Contents of 3-Monochloropropane-1,2-Diol Esters and Glycidyl Esters" 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 degree of Master of Science.

Members of the Thesis Examination Committee were as follows:

Wan Zunairah binti Wan Ibadullah, PhD
Doctor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Chairman)

Chong Gun Hean, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Internal Examiner)

Mohamed Elwathig Saeed Mirghani, PhD
Associate Professor
International Institute for Halal Research and Training
Universiti Islam Antarabangsa Malaysia
(External Examiner)

_____

RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. 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 and Biomolecular Science
Universiti Putra Malaysia
(Member)

Masni Mat Yusoff, PhD
Senior Lecturer
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

Tan Tai Boon, PhD
Senior Lecturer
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

Ahmad Jaril Asis, PhD
Head
Sime Darby Research Sdn Bhd
(Member)
Processing Technology

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Signature: _____
Name of Member of Supervisory Committee: Masni Mat Yusoff

Signature: _____
Name of Member of Supervisory Committee: Tan Tai Boon

Signature: _____
Name of Member of Supervisory Committee: Ahmad Jaril Asis

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2-MCPD	2-monochloropropane-1,2-diol
2-MCPDE	2-monochloropropane-1,2-diol esters
3-MCPD	3-monochloropropane-1,2-diol
3-MCPDE	3-monochloropropane-1,2-diol esters
AABE	Acid-activated bleaching earth
Adj MS	Adjusted mean of square
Adj SS	Adjusted sum of square
ANOVA	Analysis of variance
AOCS	American Oil Chemists' Society
AV	Anisidine value
BE	Bleaching earth
BET	Brunauer-Emmett-Teller
BJH	Barrett-Joyner-Halenda
BPO	Bleached palm oil
CCD	Central composite design
Coef.	Regression coefficient
CONTAM	Contaminants in the Food Chain
CPO	Crude palm oil
D	Composite desirability
d5	Deuterated
DAG	Diacyglycerol
df	Degree of freedom
DOBI	Deterioration of the bleachability index

EC	European Commission
EFSA	European Food Safety Authority
ELSD	Evaporative light scattering detector
EU	European Union
FESEM	Field emission scanning electron microscope
FFA	Free fatty acids
GC-MS	Gas chromatography-mass spectrometry
GE	Glycidyl esters
HP	Hydratable phosphatides
IARC	International Agency for Research on Cancer
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LOD	Limit of detection
LOQ	Limit of quantification
m/z	Mass-to-charge ratio
MAG	Monoacylglycerol
max	Maximum
MB	Middle bound
min	Minimum
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
NHP	Non-hydratable phosphatides
PFAD	Palm fatty acid distillate
pH	Potential of hydrogen
PORAM	Palm Oil Refiners Association of Malaysia
PQ	Premium quality

PV	Peroxide value
R	Coefficient of correlation
R	Redness
rac	racemate
R^2	Coefficient of determination
RBDPO	Refined, bleached and deodorized palm oil
RP-HPLC	Reverse phase-high performance liquid chromatography
RSD	Relative standard deviation
RSM	Response surface methodology
RSPO	Roundtable on Sustainable Palm Oil
S_N	Nucleophilic substitution
SQ	Superior quality
STQ	Standard quality
TAG	Triacyglycerides
TDI	Tolerable daily intake
TIC	Total ion count
UV-vis	Ultraviolet visible
w/v	Volume concentration
w/w	Mass fraction (mass/mass)

CHAPTER 1

INTRODUCTION

3-monochloropropane-1,2-diol esters (3-MCPDE) is not something new. It was first identified in its free form in acid-hydrolyzed vegetable protein and soy sauce by Velíšek et al. in 1978, and its ester form was subsequently reported in 1980 (Davidek, Velíšek, Kubelka, Janíček, & Šimicová, 1980; Velišek et al., 1980). Corresponding regulation was then introduced in order to control the maximum limit of this carcinogenic compound in food. Years later, high level of 3-MCPDE was discovered again but in edible fats and oils instead, particularly in refined palm oil (Zelinková, Svejkovská, Velíšek, & Doležal, 2006). Further studies have subsequently revealed a new type of process contaminant named glycidyl esters (GE) as a result of overestimation of 3-MCPDE analyzed by indirect methods in edible oils (Weißhaar & Perz, 2010). 3-MCPDE and GE, are both proven to be carcinogenic when they are completely hydrolyzed into their free form in human body (EFSA CONTAM Panel (European Food Safety Authority Panel on Contaminants in the Food Chain), 2016). 3-MCPD has been identified as a non-genotoxic threshold carcinogen that primarily affects kidneys and male fertility, while glycidol is known as a genotoxic non-threshold carcinogen in animal studies. As of now, the mechanisms and factors that affect the formation of both esters are still not clearly understood.

However, even with limited knowledge on these esters, new regulations regarding the maximum levels of GE in food have already been put in place since 2018. Regulation (EU) 2018/290 by the European Commission has established a maximum level of 1.0 mg/kg for GE in vegetable oils and fats, 0.5 mg/kg in infants and young children food, 0.05 mg/kg and 0.006 mg/kg in powdered and liquid infant formula, respectively, as of 1st July 2019. For 3-MCPDE, the related regulation has yet to be launched, but the European Commission has suggested two possible maximum levels for 3-MCPDE in refined vegetable oils, which are 1.25 mg/kg for oils and fats from coconut, maize, rapeseed, sunflower, soybean and palm kernel oil and the mixture of aforementioned oils and fats, and 2.50 mg/kg for other vegetable oils and fish oil and mixture of oils in this category. Palm oil falls in the second group with 2.50 mg/kg as the maximum level, but based on a survey on the commercial refined, bleached and deodorized palm olein in Malaysia market, high levels of 3-MCPDE and GE in were found, ranging from 0.34-4.45 mg/kg and 0.34-10.98 mg/kg, respectively (Sim, 2016). Refined palm oil is the major vegetable oil in the world due to its low-cost production, high oil yield and versatility in food application. It is a unique food ingredient, especially in infant formula, because of its balanced composition of different classes of fatty acids and high nutritional value. To date, no substitute ingredient has been found to replace the functions of palm oil in infant formula. As the second most consumed oil in the world after soybean oil, its genotoxicity and carcinogenicity thus bring up public health concerns and drive the need for mitigation strategies.

Generally, palm oil refining aims to remove undesirable minor constituents in oil with the least possible damage to the acylglycerols and minimal loss of the desirable constituents. Typical palm oil refining process employs physical refining process which

involves three main steps, namely degumming, bleaching and deodorization. Although it was proven that the formation of both contaminants is strongly associated with the high temperature of deodorization process, other stages of refining, such as degumming and bleaching, could affect the formation of 3-MCPDE and GE as well (WO2010063450A1, 2010). Although each stage of the physical refining process was carefully inspected via various studies, the resulting findings and suggestions proposed were not always consistent. Besides, it is even perplexing for industries as researchers believe that both 3-MCPDE and GE, are of different structural profiles and toxicology significances and therefore should be treated independently when formulating mitigation measures. This results in the development of various mitigation strategies which only take one contaminant into consideration. This makes it difficult for the industries to adopt the suggestions if both esters require different refining approaches. Most importantly, high cost incurred by the proposed strategies sets the industry back. Refiners are challenged by cost-efficient refining approach which is sustainable to produce high quality oils with guarantees of low level of contaminants, excellent nutritional quality and the least possible side-streams.

Limited knowledge, contradictory findings, lack of comprehensive mitigation approach and high cost incurred by the modified process are believed to be the main obstacles faced by current industries. Therefore, the objectives of this study were:

- To improve the pre-treatment steps (degumming and bleaching) of physical palm oil refining process for the minimal formation of 3-MCPDE and GE in RBDPO; and
- To develop and optimize a new refining process for the production of high quality RBDPO with reduced levels of 3-MCPDE and GE, while maintaining the oil qualities at the same time; and
- To evaluate the mitigation efficiency of the new refining approach.

REFERENCES

American Oil Chemists' Society. (2017). *Official methods and recommended practices of the AOCS*. (M. W. Collison, Ed.) (7th ed.). Urbana, IL: American Oil Chemists' Society.

Anderson, D. (2005). A Primer on Oils Processing Technology. In Fereidoon Shahidi (Ed.), *Bailey's Industrial Oil and Fat Products* (6th ed., pp. 1–56). Hoboken, New Jersey: John Wiley & Sons, Inc. https://doi.org/10.1002/047167849X.bio077

Appleton, D. R., & Tiong, S. H. (2019). Oil Palm Organochlorines and 3-MCPD. In *Second International Symposium on MCPD Esters and Glycidyl Esters 2019*. Berlin, Germany.

Bakhiya, N., Abraham, K., Gürtler, R., Appel, K. E., & Lampen, A. (2011). Toxicological assessment of 3-chloropropane-1,2-diol and glycidol fatty acid esters in food. *Molecular Nutrition and Food Research*, *55*(4), 509–521. https://doi.org/10.1002/mnfr.201000550

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology*, *109*(4), 289–295. https://doi.org/10.1002/ejlt.200600223

Basiron, Y., Jalani, B. S., Chan, K. W., & Lembaga Minyak Sawit Malaysia. (2000). Soils Management for Sustainable Oil Palm Cultivation. In *Advances in Oil Palm Research* (Vol. I, pp. 371–410). Kuala Lumpur, Malaysia: Malaysian Palm Oil Board,Ministry of Primary Industries, Malaysia.

Bloomer, S., Hogan, P., Lee, J. I., Matlock, M., Solheim, L., & Wicklund, L. (2010). *WO2011069028A1*. Retrieved from https://patents.google.com/patent/WO2011069028A1/en?oq=WO+2011%2F069028+A1

Boki, K., Kubo, M., Wada, T., & Tamura, T. (1992). Bleaching of alkali-refined vegetable oils with clay minerals. *Journal of the American Oil Chemists Society*, *69*(3), 232–236. https://doi.org/10.1007/BF02635892

Ceriani, R., Costa, A. M., & Meirelles, A. J. A. (2008). Optimization of the physical refining of sunflower oil concerning the final contents of trans - fatty acids. *Industrial and Engineering Chemistry Research*, *47*(3), 681–692. https://doi.org/10.1021/ie070118p

Che Man, Y. B., Haryati, T., Ghazali, H. M., & Asbi, B. A. (1999). Composition and thermal profile of crude palm oil and its products. *Journal of the American Oil Chemists' Society*, *76*(2), 237–242. https://doi.org/10.1007/s11746-999-0224-y

Chemat, S. (2017). *Edible Oils: Extraction, Processing, and Applications*. CRC Press. Retrieved from https://books.google.com.my/books?id=klAsDwAAQBAJ

Cheng, W. W., Liu, G. Q., & Liu, X. Q. (2016). Formation of Glycidyl Fatty Acid Esters Both in Real Edible Oils during Laboratory-Scale Refining and in Chemical Model during High Temperature Exposure. *Journal of Agricultural and Food Chemistry*, *64*(29), 5919–5927. https://doi.org/10.1021/acs.jafc.6b01520

Cheng, W. W., Liu, G. Q., Wang, L. Q., & Liu, Z. S. (2017). Glycidyl Fatty Acid Esters in Refined Edible Oils: A Review on Formation, Occurrence, Analysis, and Elimination Methods. *Comprehensive Reviews in Food Science and Food Safety*. Wiley/Blackwell (10.1111). https://doi.org/10.1111/1541-4337.12251

Cleenewerck, B., & Dijkstra, A. J. (1992). The Total Degumming Process – Theory and Industrial Application in Refining and Hydrogenation. *Fett Wissenschaft Technologie/Fat Science Technology*, *94*(8), 317–322. https://doi.org/10.1002/lipi.19920940809

Čmolík, J., & Pokorný, J. (2000). Physical refining of edible oils.pdf. *European Journal of Lipid Science and Technology*. WILEY-VCH Verlag GmbH. https://doi.org/10.1002/1438-9312(200008)102:7<472::AID-EJLT472>3.0.CO;2-Z

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 Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *29*(3), 354–361. https://doi.org/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. https://doi.org/10.1016/j.foodchem.2011.10.034

Crews, C., Brereton, P., & Davies, A. (2001). The effects of domestic cooking on the levels of 3-monochloropropanediol in foods. *Food Additives and Contaminants*, *18*(4), 271–280. https://doi.org/10.1080/02652030120064

Crews, C., Hough, P., Brereton, P., Harvey, D., MacArthur, R., & Matthews, W. (2002). Survey of 3-monochloropropane-1,2-diol (3-MCPD) in selected food groups, 1999-2000. *Food Additives and Contaminants*, *19*(1), 22–27. https://doi.org/10.1080/02652030110085395

Cvengros, J. (1995). Physical refining of edible oils. *Journal of the American Oil Chemists' Society*, *72*(10), 1193–1196. https://doi.org/10.1007/BF02540987

Davidek, J., Velíšek, J., Kubelka, V., Janíček, G., & Šimicová, Z. (1980). Glycerol chlorohydrins and their esters as products of the hydrolysis of tripalmitin, tristearin and triolein with hydrochloric acid. *Zeitschrift Für Lebensmittel-Untersuchung Und -Forschung*, *171*(1), 14–17. https://doi.org/10.1007/BF01044410

De Greyt, W. (n.d.). Deodorization - AOCS Lipid Library. Retrieved May 23, 2018, from http://lipidlibrary.aocs.org/OilsFats/content.cfm?ItemNumber=40326

De Greyt, W., & Kellens, M. (2005). Deodorization. In F. Shahidi (Ed.), *Bailey's industrial oil and fat products* (6th ed., Vol. 5, pp. 341–383). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/047167849X.bio027

De Greyt, W., & Papastergiadis, A. (2019). 3-MCPD Esters and Glycidyl Esters Mitigation during Industrial Oil Processing. In *DGF Symposium on MCPD Esters and Glycidyl Esters New Developement in Toxicology, Legislation, Analytics and Mitigation*. Berlin, Germany.

Department of Standards Malaysia. (2007). Palm Oil - Specification (Second Revision). *Malaysian Standard*.

Destaillats, F., Craft, B. D., Dubois, M., & Nagy, K. (2011). Glycidyl esters in refined palm (*Elaeis guineensis*) oil and related fractions. Part I: Formation mechanism. *Food Chemistry*, *132*(1), 73–79. https://doi.org/10.1016/j.foodchem.2011.10.034

Destaillats, F., Craft, B. D., Sandoz, L., & Nagy, K. (2012). Formation mechanisms of Monochloropropanediol (MCPD) fatty acid diesters in refined palm (*Elaeis guineensis*) oil and related fractions. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *29*(1), 29–37. https://doi.org/10.1080/19440049.2011.633493

Dijkstra, A. J., & Segers, J. C. (2007). Production and Refining of Oils and Fats. In Frank D. Gunstone, John L. Harwood, & Albert J. Dijkstra (Eds.), *The Lipid Handbook with CD-ROM, Third Edition* (3rd ed., pp. 143–262). CRC Press. https://doi.org/doi:10.1201/9781420009675.ch3

Dudrow, F. A. (1983). Deodorization of edible oil. *Journal of the American Oil Chemists' Society*, *60*(2), 272–274. https://doi.org/10.1007/BF02543499

Edem, D. O. (2002). Palm oil: Biochemical, physiological, nutritional, hematological and toxicological aspects: A review. *Plant Foods for Human Nutrition*, *57*(3/4), 319–341. https://doi.org/10.1023/A:1021828132707

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). (2016). Risks for human health related to the presence of 3- and 2-monochloropropanediol (MCPD), and their fatty acid esters, and glycidyl fatty acid esters in food. *EFSA Journal*, *14*(5). https://doi.org/10.2903/j.efsa.2016.4426

Ermacora, A., & Hrncirik, K. (2014). Influence of oil composition on the formation of fatty acid esters of 2-chloropropane-1,3-diol (2-MCPD) and 3-chloropropane-1,2-diol (3-MCPD) under conditions simulating oil refining. *Food Chemistry*, *161*, 383–389. https://doi.org/10.1016/j.foodchem.2014.03.130

Franke, K., Strijowski, U., Fleck, G., & Pudel, F. (2009). Influence of chemical refining process and oil type on bound 3-chloro-1,2-propanediol contents in palm oil and rapeseed oil. *LWT - Food Science and Technology*, *42*(10), 1751–1754. https://doi.org/10.1016/j.lwt.2009.05.021

Fraser, M. S., & Frankl, G. (1981). Colored components of processed palm oil. *Journal of the American Oil Chemists' Society*, *58*(10), 926–931. https://doi.org/10.1007/BF02659660

Freudenstein, A., Weking, J., & Matthäus, B. (2013). Influence of precursors on the formation of 3-MCPD and glycidyl esters in a model oil under simulated deodorization conditions. *European Journal of Lipid Science and Technology*, *115*(3), 286–294. https://doi.org/10.1002/ejlt.201200226

Gee, P. T. (2007). Analytical characteristics of crude and refined palm oil and fractions. *European Journal of Lipid Science and Technology*, *109*(4), 373–379. https://doi.org/10.1002/ejlt.200600264

German Federation for Food Law and Food Science (BLL). (2016). Toolbox for the Mitigation of 3-MCPD Esters and Glycidyl Esters in Food. Berlin, Germany: Druckerei Bloch & Co.

Gibon, V., Ayala, J. V., Dijckmans, P., Maes, J., & De Greyt, W. (2009). Future prospects for palm oil refining and modifications. *Oléagineux, Corps Gras, Lipides*, *16*(4-5–6), 193–200. https://doi.org/10.1051/ocl.2009.0268

Gibon, V., De Greyt, W., & Kellens, M. (2007). Palm oil refining. *European Journal of Lipid Science and Technology*, *109*(4), 315–335. https://doi.org/10.1002/ejlt.200600307

Goh, E. M., & Timms, R. E. (1985). Determination of mono- and diglycerides in palm oil, olein and stearin. *Journal of the American Oil Chemists' Society*, *62*(4), 730–734. https://doi.org/10.1007/BF03028741

Goh, S. H., Choo, Y. M., & Ong, S. H. (1985). Minor constituents of palm oil. *Journal of the American Oil Chemists' Society*, *62*(2), 237–240. https://doi.org/10.1007/BF02541384

Gutierrez, E., & Wang, T. (2004). Effect of processing on sphingolipid content in soybean products. *Journal of the American Oil Chemists' Society*, *81*(10), 971–977. https://doi.org/10.1007/s11746-004-1009-1

Hamlet, C. G., Jayaratne, S. M., & Matthews, W. (2002). 3-Monochloropropane-1,2-diol (3-MCPD) in food ingredients from UK food producers and ingredient suppliers. *Food Additives and Contaminants*, *19*(1), 15–21. https://doi.org/10.1080/02652030110072344

Hamlet, Colin G., Asuncion, L., Velíšek, J., Dolezal, M., Zelinkova, 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*. https://doi.org/10.1002/ejlt.201000480

Haraldsson, G. (1983). Degumming, dewaxing and refining. *Journal of the American Oil Chemists' Society*, *60*(2), 251–256. https://doi.org/10.1007/BF02543495

Hrncirik, K., & van Duijn, G. (2011). An initial study on the formation of 3-MCPD esters during oil refining. *European Journal of Lipid Science and Technology*, *113*(3), 374–379. https://doi.org/10.1002/ejlt.201000317

Hussin, F. (2013). *Acid Activation of Bleaching Earth for Crude Palm Oil Treatment*. Universiti Malaya.

Hussin, F., Aroua, M. K., & Daud, W. M. A. W. (2011). Textural characteristics, surface chemistry and activation of bleaching earth: A review. *Chemical Engineering Journal*, *170*(1), 90–106. https://doi.org/10.1016/j.cej.2011.03.065

Hymore, F. K. (1996). Effects of some additives on the performance of acid-activated clays in the bleaching of palm oil. *Applied Clay Science*, *10*(5), 379–385. https://doi.org/10.1016/0169-1317(95)00034-8

IARC Working Group on the Evaluation of Carcinogenic Risk to Humans. (2013). 3-monochloro-1,2-propanediol. In *Some Chemicals Present in Industrial and Consumer Products, Food and Drinking-Water*. (Vol. 101). Lyon, France. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK373192/

Idris, N. A., Tan, Y. A., Siew, W. L., & Lembaga Minyak Sawit Malaysia. (2005). *MPOB test method*. Kuala Lumpur: Malaysian Palm Oil Board.

Jędrkiewicz, R., Kupska, M., Głowacz, A., Gromadzka, J., & Namieśnik, J. (2016). 3-MCPD: A Worldwide Problem of Food Chemistry. *Critical Reviews in Food Science and Nutrition*, *56*(14), 2268–2277. https://doi.org/10.1080/10408398.2013.829414

Joint FAO/WHO Expert Committee, & Additives on Food (JECFA). (2002). *Evaluation of Certain Food Additives and Contaminants: Fifty-seventh Report of the Joint FAO/WHO Expert Committee on Food Additives* (... report of the Joint FAO WHO Expert Committee on Food Additives). Rome: World Health Organization. Retrieved from https://books.google.com.my/books?id=SaYsDwAAQBAJ

Juanéda, P., Brac De la Périère, S., Sébédio, J. L., & Grégoire, S. (2003). Influence of Heat and Refining on Formation of CLA Isomers in Sunflower Oil. *JAOCS, Journal of the American Oil Chemists' Society*, *80*(9), 937–940. https://doi.org/10.1007/s11746-003-0800-3

Khoo, L. E., Morsingh, F., & Liew, K. Y. (1979). The Adsorption of β-Carotene I. by bleaching earths. *Journal of the American Oil Chemists' Society*, *56*(7), 672–675. https://doi.org/10.1007/BF02660071

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. https://doi.org/10.1002/ejlt.201000313

Lai, O. M., Tan, C. P., & Akoh, C. C. (2012). *Palm oil : production, processing, characterization, and uses*. AOCS Press. Retrieved from https://books.google.com.my/books/about/Palm_Oil.html?id=ITG_ngEACAAJ&redir_esc=y

Lam, M. K., Tan, K. T., Lee, K. T., & Mohamed, A. R. (2009). Malaysian palm oil: Surviving the food versus fuel dispute for a sustainable future. *Renewable and Sustainable Energy Reviews*, *13*(6–7), 1456–1464. https://doi.org/10.1016/j.rser.2008.09.009

Liu, Y., Huang, J., & Wang, X. (2008). Adsorption Isotherms for Bleaching Soybean Oil with Activated Attapulgite. *Journal of the American Oil Chemists' Society*, *85*(10), 979–984. https://doi.org/10.1007/s11746-008-1278-y

Long, K., Jamari, M. A., Ishak, A., Yeok, L. J., Latif, R. A., Ahmadilfitri, & Lai, O. M. (2005). Physico-chemical properties of palm olein fractions as a function of diglyceride content in the starting material. *European Journal of Lipid Science and Technology*, *107*(10), 754–761. https://doi.org/10.1002/ejlt.200401129

Maclellan, M. (1983). Palm oil. *Journal of the American Oil Chemists' Society*, *60*(2Part2), 368–373. https://doi.org/10.1007/BF02543520

MacMahon, S., Begley, T. H., & Diachenko, G. W. (2013). Occurrence of 3-MCPD and glycidyl esters in edible oils in the United States. *Food Additives & Contaminants: Part A*, *30*(12), 2081–2092. https://doi.org/10.1080/19440049.2013.840805

Malaysian Palm Oil Mill Council (MPOC). (2013). Malaysian Palm Oil Industry, 3–5. Retrieved from http://www.mpoc.org.my/Malaysian_Palm_Oil_Industry.aspx

Martinus, M. P. Z., Berg, G. A. D. R., & Hijlkeline, E. (2010). *WO2011005081A1*. Retrieved from https://patents.google.com/patent/WO2011005081A1

Matthäus, B., Freudenstein, A., Pudel, F., & Rudolph, T. (2011). Final Results from the German FEI Research Project Concerning 3-MCPD Esters and Related Compounds- Mitigation Strategies. In *Final Results of the German FEI Research Project Concerning 3-MCPD Esters and Related Compounds—Mitigation Strategies*. Rotterdam, The Netherlands: Euro Fed Lipid Congress 2011.

Matthäus, B., & Pudel, F. (2013). Mitigation of 3-MCPD and glycidyl esters within the production chain of vegetable oils especially palm oil. *Lipid Technology*, *25*(7), 151–155. https://doi.org/10.1002/lite.201300288

Matthäus, B., & Pudel, F. (2014). Mitigation of MCPD and Glycidyl Esters in Edible Oils. In *Processing Contaminants in Edible Oils* (pp. 23–55). Elsevier. https://doi.org/10.1016/B978-0-9888565-0-9.50007-5

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. https://doi.org/10.1002/ejlt.201000300

Maza, A., Ormsbee, R. A., & Strecker, L. R. (1992). Effects of deodorization and steam-refining parameters on finished oil quality. *Journal of the American Oil Chemists' Society*, *69*(10), 1003–1008. https://doi.org/10.1007/BF02541066

Mba, O. I., Dumont, M.-J., & Ngadi, M. (2015). Palm oil: Processing, characterization and utilization in the food industry – A review. *Food Bioscience*, *10*, 26–41. https://doi.org/10.1016/j.fbio.2015.01.003

Mogol, B. A., & Gökmen, V. (2016). Thermal process contaminants: Acrylamide, chloropropanols and furan. *Current Opinion in Food Science*, *7*, 86–92. https://doi.org/10.1016/j.cofs.2016.01.005

Morcillo, F., Cros, D., Billotte, N., Ngando-Ebongue, G.-F., Domonhédo, H., Pizot, M., … Arondel, V. (2013). Improving palm oil quality through identification and mapping of the lipase gene causing oil deterioration. *Nature Communications*, *4*, 2160. https://doi.org/10.1038/ncomms3160

Morgan, D. A., Shaw, D. B., Sidebottom, M. J., Soon, T. C., & Taylor, R. S. (1985). The function of bleaching earths in the processing of palm, palm kernel and coconut oils. *Journal of the American Oil Chemists' Society*, *62*(2), 292–299. https://doi.org/10.1007/BF02541394

Nagy, K., Sandoz, L., Craft, B. D., & Destaillats, F. (2011). Mass-defect filtering of isotope signatures to reveal the source of chlorinated palm oil contaminants. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *28*(11), 1492–1500. https://doi.org/10.1080/19440049.2011.618467

National Toxicology Program. (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*, 1–229. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12692647

O'Brien, R. D. (2008). *Fats and Oils: Formulating and Processing for Applications* (3rd ed.). Boca Raton, FL: CRC Press. Retrieved from https://books.google.com.my/books?id=3wpHj3mvra8C&dq=phosphorus+content+in+oil+5ppm+physical+refining&source=gbs_navlinks_s

Owolarafe, O. K., Faborode, M. O., & Ajibola, O. O. (2002). Comparative evaluation of the digester–screw press and a hand-operated hydraulic press for palm fruit processing. *Journal of Food Engineering*, *52*(3), 249–255. https://doi.org/10.1016/S0260-8774(01)00112-1

Özdikicierler, O., Yemişçioğlu, F., & Saygın Gümüşkesen, A. (2016). Effects of process parameters on 3-MCPD and glycidyl ester formation during steam distillation of olive oil and olive pomace oil. *European Food Research and Technology*, *242*(5), 805–813. https://doi.org/10.1007/s00217-015-2587-7

Palm Oil Refiners Association of Malaysia. (2001). PORAM Handbook. Kuala Lumpur, Malaysia.

Patterson, H. B. W. (2009). *Bleaching and purifying fats and oils : theory and practice*. (G. R. List, Ed.) (2nd ed.). AOCS Press. Retrieved from https://books.google.com.my/books?id=OzZfCgAAQBAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Paulsen, H., & Meyborg, H. (1975). Carboxoniumverbindungen in der Kohlenhydratchemie, XXV. Darstellung von Acyloxonium-Ionen durch Einwirkung von Trifluormethansulfonsäure auf Diol- und Triolester. *Chemische Berichte*, *108*(10), 3176–3189. https://doi.org/10.1002/cber.19751081008

Pudel, F., Benecke, P., Fehling, P., Freudenstein, A., Matthäus, B., & Schwaf, A. (2011). On the necessity of edible oil refining and possible sources of 3-MCPD and glycidyl esters. *European Journal of Lipid Science and Technology*, *113*(3), 368–373. https://doi.org/10.1002/ejlt.201000460

Rahn, A. K. K., & Yaylayan, V. A. (2011a). Monitoring cyclic acyloxonium ion formation in palmitin systems using infrared spectroscopy and isotope labelling technique. *European Journal of Lipid Science and Technology*, *113*(3), 330–334. https://doi.org/10.1002/ejlt.201000426

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

Ramli, M. R., Siew, W. L., Ibrahim, N. A., Hussein, R., Kuntom, A., Razak, R. A. A., & Nesaretnam, K. (2011). Effects of degumming and bleaching on 3-MCPD esters formation during physical refining. *JAOCS, Journal of the American Oil Chemists' Society*, *88*(11), 1839–1844. https://doi.org/10.1007/s11746-011-1858-0

Raznim, R. A., Kuntom, A., Siew, W. L., Ibrahim, N. A., Ramli, M. R., Hussein, R., & Nesaretnam, K. (2012). Detection and monitoring of 3-monochloropropane-1,2-diol (3-MCPD) esters in cooking oils. *Food Control*, *25*(1), 355–360. https://doi.org/10.1016/j.foodcont.2011.10.058

Richardson, L. L. (1978). Use of bleaching, clays, in processing edible oils. *Journal of the American Oil Chemists' Society*, *55*(11), 777–780. https://doi.org/10.1007/BF02682647

Sabah, E., Çinar, M., & Çelik, M. S. (2007). Decolorization of vegetable oils: Adsorption mechanism of β-carotene on acid-activated sepiolite. *Food Chemistry*, *100*(4), 1661–1668. https://doi.org/10.1016/J.FOODCHEM.2005.12.052

Sampaio, K. A., Ayala, J. V., Silva, S. M., Ceriani, R., Verhé, R., & Meirelles, A. J. A. (2013). Thermal Degradation Kinetics of Carotenoids in Palm Oil. *Journal of the American Oil Chemists' Society*, *90*(2), 191–198. https://doi.org/10.1007/s11746-012-2156-1

Sarier, N., & Güler, Ç. (1988). β-Carotene adsorption on acid-activated montmorillonite. *Journal of the American Oil Chemists' Society*, *65*(5), 776–779. https://doi.org/10.1007/BF02542530

Schurz, K. (2010). *WO2010063450A1*. Retrieved from https://patents.google.com/patent/WO2010063450A1/en

Seefelder, W., Varga, N., Studer, A., Williamson, G., Scanlan, F. P., & Stadler, R. H. (2008). Esters of 3-chloro-1,2-propanediol (3-MCPD) in vegetable oils: Significance in the formation of 3-MCPD. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *25*(4), 391–400. https://doi.org/10.1080/02652030701385241

Seefelder, Walburga, Scholz, G., & Schilter, B. (2011). Structural diversity of dietary fatty esters of chloropropanols and related substances. *European Journal of Lipid Science and Technology*, *113*(3), 319–322. https://doi.org/10.1002/ejlt.201000319

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. https://doi.org/10.1002/ejlt.201200078

Shiro, H., Kondo, N., Kibune, N., & Masukawa, Y. (2011). Direct method for quantification of glycidol fatty acid esters in edible oils. *European Journal of Lipid Science and Technology*, *113*(3), 356–360. https://doi.org/10.1002/ejlt.201000395

Siew, W. L., & Cheah, K. Y. (2007). Optimization of Degumming with Attapulgite and Acid-Activated Clays in Refining Palm Oil. *Journal of Oil Palm Research*, *19*, 373–380. Retrieved from http://jopr.mpob.gov.my/wp-content/uploads/2013/09/joprv19june2007-siew21.pdf

Siew, W. L., & Ng, W.-L. (1995). Diglyceride content and composition as indicators of palm oil quality. *Journal of the Science of Food and Agriculture*, *69*(1), 73–79. https://doi.org/10.1002/jsfa.2740690112

Silva, S. M., Sampaio, K. A., Ceriani, R., Verhé, R., Stevens, C., De Greyt, W., & Meirelles, A. J. A. (2014). Effect of type of bleaching earth on the final color of refined palm oil. *LWT - Food Science and Technology*, *59*(2P2), 1258–1264. https://doi.org/10.1016/j.lwt.2014.05.028

Sim, B. I. (2016). *Formation and Mitigation of 3-Monochloropropane-1,2-diol Esters and Glycidyl Esters in Refined Edible Palm Oil*. Universiti Putra Malaysia.

Sim, B. I., Muhamad, H., Lai, O. M., Abas, F., Yeoh, C. B., Nehdi, I. A., … Tan, C. P. (2018). New Insights on Degumming and Bleaching Process Parameters on The Formation of 3-Monochloropropane-1,2-Diol Esters and Glycidyl Esters in Refined, Bleached, Deodorized Palm Oil. *Journal of Oleo Science J. Oleo Sci*, *67*(4), 397–406. https://doi.org/10.5650/jos.ess17210

Šmidrkal, J., Tesařová, M., Hrádková, I., Berčíková, M., Adamčíková, A., & Filip, V. (2016a). Mechanism of formation of 3-chloropropan-1,2-diol (3-MCPD) esters under conditions of the vegetable oil refining. *Food Chemistry*, *211*, 124–129. https://doi.org/10.1016/j.foodchem.2016.05.039

Šmidrkal, J., Tesařová, M., Hrádková, I., Berčíková, M., Adamčíková, A., & Filip, V. (2016b). Mechanism of formation of 3-chloropropan-1,2-diol (3-MCPD) esters under conditions of the vegetable oil refining. *Food Chemistry*, *211*, 124–129. https://doi.org/10.1016/J.FOODCHEM.2016.05.039

Svejkovská, B., Novotný, O., Divinová, V., Réblová, Z., Dolezal, M., & Velísek, J. (2004). Esters of 3-Chloropropane-1 , 2-Diol in Foodstuffs. *Czech Journal of Food Science*, *22*(5), 190–196.

Swoboda, P. A. T. (1985). Chemistry of refining. *Journal of the American Oil Chemists' Society*, *62*(2), 287–292. https://doi.org/10.1007/BF02541393

Tan, C. P., Zulkurnain, M., & Lai, O. M. (2012). *WO2014081279A1*. Retrieved from https://patents.google.com/patent/WO2014081279A1/en?

Tandy, D. C., & Mcpherson, W. J. (1984, July). Physical refining of edible oils.pdf. *Journal of the American Oil Chemists Society*. https://doi.org/10.1007/BF02636265

Tareke, E., Rydberg, P., Karlsson, P., Eriksson, S., & Törnqvist, M. (2002). Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *Journal of Agricultural and Food Chemistry*, *50*(17), 4998–5006. https://doi.org/10.1021/jf020302f

Taylor, D. R. (2005). Bleaching. In Fereidoon Shahidi (Ed.), *Bailey's Industrial Oil and Fat Products* (pp. 285–339). Wiley. Retrieved from https://www.scopus.com/record/display.uri?eid=2-s2.0-57649222188&origin=inward

Taylor, D. R., Ungermann, C. B., & Demidowicz, Z. (1984). The adsorption of fatty acids from vegetable oils with zeolites and bleaching clay/zeolite blends. *Journal of the American Oil Chemists' Society*, *61*(8), 1372–1379. https://doi.org/10.1007/BF02542246

The Commission of The European Communities. Commission regulation (EC) No 1881/2006, Pub. L. No. L 364/5, Official Journal of the European Union (2006). Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32006R1881

Thomas, A., Matthäus, B., & Fiebig, H.-J. (2015). Fats and Fatty Oils. In *Ullmann's Encyclopedia of Industrial Chemistry* (pp. 1–84). Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA. https://doi.org/10.1002/14356007.a10_173.pub2

Tiong, S. H., Saparin, N., Teh, H. F., Ng, T. L. M., Md Zain, M. Z. Bin, Neoh, B. K., … Appleton, D. R. (2018). Natural Organochlorines as Precursors of 3-Monochloropropanediol Esters in Vegetable Oils. *Journal of Agricultural and Food Chemistry*, *66*(4), 999–1007. https://doi.org/10.1021/acs.jafc.7b04995

Velíšek, J., Davidek, J., Hajšlová, J., Kubelka, V., Janíček, G., & Mánková, B. (1978). Chlorohydrins in protein hydrolysates. *Zeitschrift Für Lebensmittel-Untersuchung Und -Forschung*, *167*(4), 241–244. https://doi.org/10.1007/BF01135595

Velišek, J., Davidek, J., Janiček, G., Svobodova, Z., Simicova, Z., & Kubelka, V. (1980). New Chlorine-Containing Organic Compounds in Protein Hydrolysates. *Journal of Agricultural and Food Chemistry*, *28*(6), 1142–1144. https://doi.org/10.1021/jf60232a022

Velíšek, J., Davídek, T., Davídek, J., Kubelka, V., & Víden, I. (1991). 3-Chloro-1,2-propanediol Derived Amino Acids in Protein Hydrolysates. *Journal of Food Science*, *56*(1), 139–142. https://doi.org/10.1111/j.1365-2621.1991.tb07995.x

Velíšek, J., Doležal, M., Crews, C., & Dvorák, T. (2002). Optical Isomers of Chloropropanediols : Mechanisms of their Formation and Decomposition in Protein Hydrolysates. *Czech Journal of Food Science*, *20*(5), 161–170.

Wahle, K. W. J., Heys, S. D., & Rotondo, D. (2004, November 1). Conjugated linoleic acids: Are they beneficial or detrimental to health? *Progress in Lipid Research*. Pergamon. https://doi.org/10.1016/j.plipres.2004.08.002

Weißhaar, R. (2008). 3-MCPD-esters in edible fats and oils - A new and worldwide problem. *European Journal of Lipid Science and Technology*, *110*(8), 671–672. https://doi.org/10.1002/ejlt.200800154

Weißhaar, R. (2011). Fatty acid esters of 3-MCPD: Overview of occurrence and exposure estimates. *European Journal of Lipid Science and Technology*, *113*(3), 304–308. https://doi.org/10.1002/ejlt.201000312

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. https://doi.org/10.1002/ejlt.200900137

Yeoh, C. B., & Chong, C. L. (2009). Acephate, methamidophos and monocrotophos residues in a laboratory-scale oil refining process. *European Journal of Lipid Science and Technology*, *111*(6), 593–598. https://doi.org/10.1002/ejlt.200800262

You, L. L., Baharin, B. S., Man, Y. B. C., & Takagi, S. (2001). Effect of degumming process on chromatographic separation of carotenes from crude and degummed palm oil. *Journal of Food Lipids*, *8*(1), 27–35. https://doi.org/10.1111/j.1745-4522.2001.tb00181.x

Zelinková, Z., Svejkovská, B., Velíšek, J., & Doležal, M. (2006). Fatty acid esters of 3-chloropropane-1,2-diol in edible oils. *Food Additives and Contaminants*, *23*(12), 1290–1298. https://doi.org/10.1080/02652030600887628

Zhang, X., Gao, B., Qin, F., Shi, H., Jiang, Y., Xu, X., & Yu, L. (2013). Free radical mediated formation of 3-monochloropropanediol (3-MCPD) fatty acid diesters. In *Journal of Agricultural and Food Chemistry* (Vol. 61, pp. 2548–2555). https://doi.org/10.1021/jf305252q

Zhang, Z., Gao, B., Zhang, X., Jiang, Y., Xu, X., & Yu, L. (2015). Formation of 3-monochloro-1,2-propanediol (3-MCPD) Di- and monoesters from tristearoylglycerol (TSG) and the potential catalytic effect of Fe2+ and Fe3+. *Journal of Agricultural and Food Chemistry*, *63*(6), 1839–1848. https://doi.org/10.1021/jf5061216

Zschau, W. (2001). Bleaching of edible fats and oils. *European Journal of Lipid Science and Technology*, *103*(8), 505–551. https://doi.org/10.1002/1438-9312(200108)103:8<505::AID-EJLT505>3.0.CO;2-7

Zulkurnain, M., Lai, O. M., Latip, R. A., Nehdi, I. A., Ling, T. C., & Tan, C. P. (2012). The effects of physical refining on the formation of 3-monochloropropane-1, 2-diol esters in relation to palm oil minor components. *Food Chemistry*, *135*(2), 799–805. https://doi.org/10.1016/j.foodchem.2012.04.144

Zulkurnain, M., Lai, O. M., Tan, S. C., Abdul Latip, R., & Tan, C. P. (2013). Optimization of palm oil physical refining process for reduction of 3-monochloropropane-1,2-diol (3-MCPD) ester formation. *Journal of Agricultural and Food Chemistry*, *61*(13), 3341–3349. https://doi.org/10.1021/jf4009185

BIODATA OF STUDENT

Born on October 17th 1992, Hew Khai Shin received her primary education and higher education in Seremban, Negeri Sembilan. She then completed her pre-university programme and obtained the Malaysian Higher Education Certificate (STPM). With that, she enrolled in Universiti Putra Malaysia (UPM) for the programme of Bachelor of Food Science and Technology. Graduated as a first class recipient, she was awarded with "*Hadiah Dewina*" in faculty level, which is an award for potential researcher award for her final year project titled "Effect of Mild Heat Treatment and Types of Adsorbent on the Odour Removal of Virgin Coconut Oil" in 2016. In the same year, she received the Royal Education Award/ *Anugerah Pelajaran Diraja* awarded by the Conference of Rulers/ *Majlis Raja-Raja* for her excellent performance in academic and extracurricular field throughout her bachelor degree. Before she further her postgraduate studies in 2018, she joined the working industry as a management trainee in research and development department to gain some industrial exposure. After a year, she was funded by Yayasan Sime Darby to pursue the Master of Science programme in the field of Food Technology in UPM.

LIST OF PUBLICATIONS

Hew, K. S., Asis, A. J., Tan, T. B., Yusoff, M. M., Lai, O. M., Nehdi, I. A., & Tan, C. P. (2020). Revising degumming and bleaching processes of palm oil refining for the mitigation of 3-monochloropropane-1,2-diol esters (3-MCPDE) and glycidyl esters (GE) contents in refined palm oil. *Food Chemistry*, *307*. https://doi.org/10.1016/j.foodchem.2019.125545

Hew, K. S., Asis, A. J., Tan, T. B., Yussoff, M. M., Lai, O. M., Nehdi, I. A., & Tan, C. P. (2020). Optimization of modified palm oil refining process for the reduction of 3-monochloropropane-1,2-diol esters (3-MCPDE) and glycidyl esters (GE) contents in refined palm oil. (Under review).

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