Journal of Developments in Sustainable Agriculture 10: 107–114 (2015)

Sustainable Development of the Palm Oil Industry via Process Improvement and Product Diversification

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Palm oil has been a key driver for economic development in producing countries in Southeast Asia, especially Malaysia and Indonesia, and the rapid growth of the palm oil industry has played an important role in the Malaysian economy. The sustainability concept is having a huge impact in the palm oil industry as it faces unprecedented scrutiny from governments, regulators, investors, and consumers in terms of how its business practices, supply chain, and products impact the environment. This paper gives an overview of recent research developments in refining processes and product diversification. Recent technologies for the preparation of oils, fats, and their derivatives using palm oil as a starting material are discussed. Research in the following areas is reviewed: (1) development of low free fatty acid crude palm oil; (2) refining process improvements to reduce 3-monochloropropane-1,2-diol and glycidol levels; (3) development of new palm-based emulsion products; and (4) production of palm-based functional lipids. Continuous improvements in our understanding of the refining process of this major edible oil will play an important role in the sustainable development of the palm oil industry. Safety and health issues related to palm oil products are also closely related to the sustainable development of the palm oil industry.

Key words: emulsion, palm oil, product development, 3-MCPD esters

Introduction

Palm oil is a liquid extracted from the fleshy orange-red mesocarp of the fruit of the oil palm tree, which contains 45–55% oil. The production of palm oil currently has surpassed that of soybean oil (SBO) to be ranked first in the worldwide production of edible oils. Most of the world's production of palm oil comes from Southeast Asia, in particular Indonesia and Malaysia. The oil palm tree is a perennial tree crop that yields an average of 3.8 tonnes of oil per hectare per year in Malaysia (MPOB, 2013). Palm oil is known as the "golden crop" and had a production of about 19.4 and 31 million tonnes in 2013 in Malaysia and Indonesia, respectively (Indexmundi.com, 2013). Table 1 shows annual production for Malaysia and Indonesia from 2003 to 2014. In 2013, total palm oil exports from Malaysia were 18.1 million tonnes (MPOB, 2013). As of 2013, the total area of oil palm plantation in Malaysia was approximately 5.23 million ha (Table 2). Malaysia and Indonesia currently account for about 85% of global production (Sime Darby, 2014). Other producer countries include Thailand, Colombia, Nigeria, Papua New Guinea, and Ecuador. Since 2006, Indonesia surpassed Malaysia in production of palm oil to become the world's leading producer, and Indonesia's production rate should continue to outpace Malaysia for the foreseeable future.

Palm oil is mainly made up of triacylglycerols, a small amount of partial acylglycerols (4–7%), and some minor components that form the unsaponifiable fraction. Palm oil can be fractionated into liquid olein and solid stearin (Siew, 2004). It has approximately equal amounts of saturated fatty acids and unsaturated fatty acids. It also has triacylglycerols with varying melting points, so it has a wide plastic range and the required consistency without the need for hydrogenation. Because it also has natural antioxidants such

Received: September 18, 2014, Accepted: March 27, 2015
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as carotenoids, tocopherols, and tocotrienols, palm oil has reasonably good resistance to oxidation and, therefore, a long shelf life.

The sustainability concept currently is having a huge impact in palm oil industry as it faces unprecedented scrutiny from governments, regulators, investors, and consumers in terms of how its business practices, supply chain, and products impact the environment. This paper gives an overview of recent research developments in refining processes and product diversification in the palm oil industry. Recent technologies for the preparation of oils, fats, and their derivatives using palm oil as a starting material are also discussed.

Development of low free fatty acid crude palm oil

Oil palm is the highest yielding oil crop, producing on average about 4–5 tonnes of oil per hectare per year, about 10 times the yield of SBO (Basiron, 2007). In a palm oil mill, the extraction of crude palm oil is carried out at temperatures ranging from 90 to 140℃. Palm fruit bunches are first treated in a sterilizer where saturated steam at a pressure of 3 kg/cm^2 and a temperature of 140℃ is introduced (Corley and Tinker, 2003). Sterilization serves two main purposes: it prevents free fatty acid (FFA) build-up in the oil and it loosens or separates the fruit on the bunch to facilitate stripping. Separated fruits are then heated in a digester at a temperature of 95–100℃ to separate the mesocarp of the nut hulls from the nuts. Crude palm oil is extracted with a screw press under high pressure and then clarified to remove unwanted materials. FFA content of crude palm oil has been reported to range from 2.3 to 6.7% (Saad *et al*., 2006). Purseglove (1985) stated that poor and lengthy storage of fruits will lead to a considerable increase in FFA. The crude palm oil is further processed to remove, among other things, a significant quantity of FFA and to obtain refined, bleached, and deodorized palm oil (RBDPO). The FFA content of RBDPO should be lower than 0.1% according to Palm Oil Refiners Association of Malaysia (PORAM) standard specifications (Tan, 1994).

More recently Tan *et al*. (2009) used drying as a substitute for sterilization as a pretreatment prior to the extraction of low free fatty acid crude palm oil (low-FFA-CPO). Production of very low levels of FFA in low-FFA-CPO is expected to negate the need for chemical processing. In Tan *et al*.'s study, the response surface methodology was used to optimize conditions for the drying of spikelets for the production of low-FFA-CPO. Combinations of temperature and time were examined to optimize the drying process. They found that the drying should be carried out at 66.8℃ for 12.8 h. Under these optimum conditions, the oil yield was ＞30% and the FFA level was ＜1%. Results of this study could be used as a guide for pilot-scale production of low-FFA-CPO. The reduction in the FFA level was significant ($P<0.05$) as compared to standard commercial CPO, and the drying technique is environmentally friendly because no chemicals are used in the production of the low-FFA-CPO.

A residual oil recovery system from pressed mesocarp fibers was developed by Vijaya *et al*. (2013). In general, pressed mesocarp fibers retain about 5.0–11.0

Table 1. Production of crude palm oil by Malaysia and Indonesia, 2004–2013.

Year	Malaysia (1000 MMT)	Indonesia (1000 MMT)
2004	15,194	13,560
2005	15,485	15,560
2006	15,290	16,600
2007	17,567	18,000
2008	17,259	20,500
2009	17,763	22,000
2010	18,211	23,600
2011	18,202	26,200
2012	19,321	28,500
2013	19,400	31,000

(Source: Indexmundi.com. 2013 Retrieved 15 September 2014)

Table 2. Malaysian oil palm area (million hectares).

Year	Malaysia
1975	0.64
1980	1.02
1985	1.48
1990	2.03
1995	2.54
2000	3.37
2005	4.05
2010	4.85
2013	5.23

(Source: MPOB, 2013)

% (dry basis) of residual oil. Using the developed system, Vijaya *et al*. were able to recover residual oil in the pressed mesocarp fibers by using a washing technique, followed by additional pressing to recover the residual oil. With this system, they were able to reduce the residual oil content in the pressed mesocarp fiber to as low as 2.0% on a dry basis and recover additional 0.15% to 0.45% of oil per tonne of palm fruit bunches. The extracted CPO from the pressed mesocarp fibers exhibited even better oil quality than CPO extracted by standard methods.

Reducing 3-monochloropropane-1,2-diol (3-MCPD) and glycidol levels

Fatty acid esters of 3-MCPD and glycidol were classified as a new class of food contaminants after they were found to be widely distributed in the food chain. These processed contaminants are of great concern because they are thought to be hydrolyzed completely into their free forms, namely 3-MCPD and glycidol, which are carcinogenic and can jeopardize human health. RBDPO is the major dietary source of both 3-MCPD esters and glycidyl esters because it is widely used as a common ingredient or medium in various food products (Crews *et al*., 2013). Thus, developing mitigation strategies for 3-MCPD esters and glycidyl esters during RBDPO production is an important issue for global food security. 3-MCPD esters have been found in refined edible oils (Zelinková *et al*., 2006) and in many processed foods, including infant formulas (Hamlet *et al*., 2002; Divinová *et al*., 2004; Hamlet and Sadd, 2004; Doležal *et al*., 2005; Zelinková *et al*., 2009a, b).

Due to its toxicity, 3-MCPD has been extensively monitored in acid-hydrolyzed vegetable proteins and regulatory limits were established in 2001 by the European Commission and other regulatory bodies worldwide, including China and Japan (EC, 2001; JECFA, 2001; EFSA, 2008).

3-MCPD esters are formed at high temperatures during the oil refining process, mainly during the deodorization step, and the highest levels are reported in refined palm oil (4.5–13 ppm; Franke *et al*., 2009). Research needs to address both the refining process and the formation mechanism of these chloroesters in fats and oils to develop mitigation strategies for minimizing the contaminants from the oil refining process. Zulkurnain *et al*. (2012, 2013) studied the effect of the physical refining process of CPO on 3-MCPD esters, including analytical aspects, processing factors, and related precursors that contribute to the formation of 3-MCPD esters. They found that the modification of the physical refining process with the incorporation of a water degumming and washing step after acid degumming and the addition of a mixture of magnesium silicate and activated clay for bleaching reduced the formation of 3-MCPD esters. In addition, optimization of the modified refining process using response surface methodology resulted in RBDPO of comparable quality but with a reduced level of formation of 3-MCPD esters as compared with the conventional refining process. The formation of 3-MCDP esters increased as the temperature increased from 180 to 250 ℃ during deodorization, but a higher temperature (270 ℃) caused significant ($P<0.05$) degradation of the compound. The quality of the CPO significantly ($P<0.05$) influenced the level of 3-MCPD ester formation.

Development of new palm-based emulsion products

Most emulsion food systems basically exist in a form that consists of two immiscible liquids (usually oil and water), with one of the liquids dispersed as small spherical droplets. An oil-water emulsion is generally defined as a three-part system consisting of a hydrophobic fat or oil phase, an aqueous phase, and an interface in which surface-active compounds bridge the two phases (Dalgeish, 2006). Concentrated oil-water emulsions such as mayonnaise normally contain as much as 80% oil in the dispersed phase. As opposed to dilute emulsions with a low oil content, the droplets in concentrated emulsions are crowded together, making the interaction between adjacent droplets important. For this reason, the rheological properties and degree of stability of these emulsions are appreciably different from emulsions with a lower oil content. A variety of oils have been used to produce mayonnaise, including canola, sunflower, cottonseed, and olive oil, as well as SBO (Martínez *et al*., 2007).

SBO is one of the major oils used in emulsion products such as margarine, salad dressings, and mayonnaises. Previous studies have shown that blending of SBO with other oils/fats can improve the overall properties (Driscoll *et al*., 2001) and oxidative stability (Nor Hayati *et al*., 2005) of the emulsion systems. One oil that can be blended with SBO is palm kernel olein (PKO), a low melting fraction of palm kernel oil. Nor Hayati *et al*. (2005, 2007, 2009a, b) demonstrated that incorporation of PKO in the dispersed phase volume fraction can improve the oxidative stability of SBO-based emulsions and, to an extent, their physical stability. They found that the substitution of SBO with 10–40% PKO in the dispersed phase volume fraction caused alterations of the droplet size and rheological characteristics of the evaluated emulsions. Substitution of SBO with up to 30% PKO provided better stability in the emulsions when stored at 25℃ for 30 days. The improved stability was attributed to a structural rearrangement, which strengthened the network within the droplets of the emulsions. The relative high C6–C12 fatty acid content of PKO is thought to at least partly contribute to the structural rearrangement and thus lead to better miscibility between the dispersed and continuous phases. These studies show that the benefits derived from the use of SBO in emulsion products can be preserved while stability can be improved with the addition of PKO.

Recently, palm olein-based diacylglycerol (POL-DAG) oil obtained through enzymatic glycerolysis and purification processes has been used in a variety of applications in the food industry. POL-DAG oil has demonstrated higher emulsification and water-retention capacities as compared with those of triacylglycerol oil (Shimada and Ohashi, 2003). As a result, POL-DAG blends with SBO or virgin coconut oil can also be incorporated into oil-water emulsions to produce sauces, mayonnaises, and salad dressings, in addition to water-oil emulsion products such as margarines, spreads, and other food products. Consequently, the development of an oil-water emulsion food model containing POL-DAG with SBO or virgin coconut oil will also allow for dramatic growth in the market. Studies on blends of palm oil-based DAG and several other oils and fats have been conducted, and the overall properties in emulsion products, such as margarines and spreads, have been shown to improve (Cheong *et al*., 2010; Saberi *et al*., 2012).

Ng *et al*. (2014) showed that substituting virgin coconut oil with different amounts of POL-DAG oil (10–30 wt%) in the dispersed phase of concentrated oil-water emulsions affected their rheological properties, droplet sizes, textural properties, colors, and microstructures. Overall, emulsion blends of POL-DAG/virgin coconut oil with improved nutritional properties are expected to create interest in the food industry because of the large number of potential applications.

Production of palm-based functional lipids

Modification of oil after the refining process is one of the most commonly used approaches to diversify the product range of edible oils. Such modifications are important in improving consumer perceptions and uses of palm oil in various food applications. Structurally defined lipids have been developed to meet the demand of health-conscious consumers (Lai *et al*., 2005). These oils contain lipids that have been restructured by changing the positions and composition of fatty acids from their native state. In general, structured lipids are triacylglycerols containing short-, medium-, and long-chain fatty acids, preferably on the same glycerol molecule to exhibit maximum efficiency (Akoh, 1995). Lipids such as these are not created in in nature and cannot be produced by chemical reactions. They can only be synthesized by enzymatic methods using *sn*-1, 3 specific lipase (Fomuso and Akoh, 1997). Table 3 lists some lipase-mediated palm-based structured lipids recently reported in the literature (2003–2013).

DAGs are esters of glycerol in which two of the hydroxyl groups are esterified with fatty acids. They are present in two different isomeric forms: 1,2 (2,3) DAG and 1,3 DAG. The latest application of DAG oil is being marketed as a cooking oil in Japan and the United States (Flickinger and Matsuo, 2003). DAGs can decrease the postprandial lipid level, suppress accumulation of visceral abdominal fat, and reduce body weight. DAGs can be produced enzymatically through esterification, glycerolysis, and partial hydrolysis.

Cheong *et al*. (2007) studied the production of high-purity diacylglycerol oil by lipase-catalyzed partial hydrolysis. Response surface methodology was applied to optimize the reaction conditions, namely water content, enzyme load, reaction temperature, and reaction time, to produce a high DAG, low triacylglycerol oil. In this study, all the reaction conditions showed positive effects on DAG yield, with enzyme load having the greatest effect followed by reaction temperature, water content, and reaction time.

Lipase-catalyzed partial hydrolysis at the optimal conditions (50 wt% water content, 10 wt% enzyme load, 65℃ reaction temperature, and 12 h reaction time) can be up-scaled to a 9 kg continuous production using a packed bed bioreactor to produce an oil containing 32 wt% DAG. In general, purification of the produced oil using short path distillation yielded a DAG-enriched

Table 3. Lipase-mediated palm-based structured lipids.

Process/Product	Reference
Trans-free structured margarine from high stearate soybean oil and palm stearin	Pande and Akoh, 2013
Cottonseed oil and palm stearin-based structured lipid for trans-free margarine	Pande *et al*., 2013
Enrichment of palm olein with long-chain polyunsaturated fatty acids	Nagachinta and Akoh, 2012
Interesterified structured lipid for soft margarine	Zhu *et al*., 2012
Zero-trans fat margarine using pine nut oil and palm stearin	Adhikari *et al*., 2010
Cocoa butter alternative from coconut oil fraction and palm oil fraction	Bae *et al*., 2010
Trans-free margarine stock from avocado and palm oils	Lee and Lee, 2009
Diacylglycerol-enriched palm olein	Cheong *et al*., 2007
Glycerolysis of palm olein for monoacylglycerol production	Cheirsilp *et al*., 2007
Interesterification of virgin olive oil with a fully hydrogenated fat in a batch reactor	Criado *et al*., 2007
Hydrolysis of palm and olive oils by immobilized lipase using hollow fiber reactor	Shamel *et al*., 2007
Lipase-catalyzed interesterification of palm stearin with canola oil blends	Siew *et al*., 2007
Lipase-catalyzed production of medium-chain triacylglycerols from palm kernel oil distillate	Low *et al*., 2007
Structured lipids produced from palm kernel fat and fish oil	Gamboa and Gioielli, 2006
Enzymatic hydrolysis of crude palm olein by lipase from *Candida rugosa*	You and Baharin, 2006
Enzymatic incorporation of stearic acid into a blend of palm olein and palm kernel oil	Lumor and Akoh, 2005a
Lipase-catalyzed acidolysis of palm olein and caprylic acid in a continuous bench-scale packed bed bioreactor	Lai *et al*., 2005
Lipase-catalyzed interesterification of palm stearin with soybean oil in a continuous fluidized-bed reactor	Osório *et al*., 2005
Incorporation of γ-linolenic and linoleic acids into a palm kernel oil/palm olein blend	Lumor and Akoh, 2005b
Synthesis of mixed esters of ascorbic acid using methyl esters of palm and soybean oils	Hsieh *et al*., 2005
Production of medium chain glycerides from coconut and palm kernel fatty acid distillates by lipase-catalyzed reactions	Nandi *et al*., 2005
Continuous production of monoacylglycerols by glycerolysis of palm olein with immobilized lipase	Kaewthong *et al*., 2005
Enzymatic glycerolysis of palm and palm kernel oils	Tüter and Aksoy, 2005
Diacylglycerols from palm oil deodorizer distillate	Lo *et al*., 2004
Synthesis of the structured lipid 1,3-dioleoyl-2-palmitoylglycerol from palm oil	Chen *et al*., 2004
Lipase-catalyzed incorporation of n-3 polyunsaturated fatty acids into palm oil	Ramírez Fajardo *et al*., 2003
Production of cocoa-butter-like fats by the lipase-catalyzed interesterification of palm oil and hydrogenated soybean oil	Abigor *et al*., 2003
Enzymatic transesterification with flaxseed oil on the high-melting glycerides of palm stearin and palm olein	Long *et al*., 2003
Synthesis of 2-monoglycerides by alcoholysis of palm oil and tuna oil using immobilized lipases	Wongsakul *et al*., 2003

palm olein with a 60 wt% DAG and 40 wt% triacylglycerol content, which is suitable for use in margarine, spread, or shortening applications.

Conclusion

Ongoing process improvements and product diversification in the palm oil industry will play an important role in the sustainable development of the industry. The utilization of palm oil products in various complex food and nonfood systems requires constant improvements of our knowledge of the processing technology of palm oil and its components. In addition, product diversification in the palm oil industry also requires a substantial understanding of the physicochemical properties of this globally important edible oil. Safety and health issues related to palm oil products are also closely related to the basic chemical components of palm oil. Recent safety issues, such as the presence of 3-MCPD and glycidol esters in refined palm oil products, should also be addressed through in-depth studies of the interactions between the basic components in the unrefined oil and external precursors.

References

Abigor, R. D., Marmer, W. N., Foglia, T. A., Jones, K. C., DiCiccio, R. J., Ashby, R. et al., 2003. Production of cocoa butter-like fats by the lipase-catalyzed interesterification of palm oil and hydrogenated soybean oil. J. Am. Oil Chem. Soc. 80, 1193–1196.

Adhikari, P., Zhu, X.M., Gautam, A., Shin, J.A., Hu, J.N., Lee, J.H., Akoh, C.C., Lee, K.T., 2010. Scaled-up production of zero-trans margarine fat using pine nut oil and palm stearin. Food Chem. 119, 1332–1338.

Akoh, C. C., 1995. Structured lipids-enzymatic approach. INFORM, 6, 1055–1061.

Bae, S.K., Lee, K.S., Lee, K.T., 2010. Synthesis of cocoa butter alternative from coconut oil fraction and palm oil fractions by lipase-catalyzed interesterification. J. Korean Soc. Food Sci. Nutr. 39, 1487–1494.

Basiron, Y., 2007. Palm oil production through sustainable plantations. Eur. J. Lipid Sci. Technol. 109, 289–295.

Cheirsilp, B., Kaewthong, W., H-Kittikun, A., 2007. Kinetic study of glycerolysis of palm olein for monoacylglycerol production by immobilized lipase. Biochem. Eng. J. 35, 71–80.

Chen, M., Vali, S. R., Lin, J., Ju, Y., 2004. Synthesis of the structured lipid 1, 3-dioleoyl-2-palmitoylglycerol from palm oil. J. Am. Oil Chem. Soc. 81, 525–532.

Cheong, L.Z., Tan, C.P., Long, K., Yusoff , M.S.A., Lo, S.K., Lai, O.M., 2007. Production of a diacylglycerol-enriched palm olein using lipase-catalyzed partial hydrolysis: Optimization using response surface methodology. Food Chem. 105, 1614–1622.

Cheong, L.Z., Tan, C.P., Long, K., Yusoff, M.S.A., Lai, O.M., 2010. Physicochemical, textural and viscoelastic properties of palm diacylglycerol bakery shortening during storage. J. Sci. Food Agric. 90, 2310–2317.

Corley, R. H. V., Tinker, P. B., 2003. The oil palm. USA: Blackwell, pp. 450–471.

Crews, C., Chiodini, A., Granvogl, M., Hamlet, C., Hrnčiřík, K., Kuhlmann, J., Lampen, A., Scholz, G., Weisshaar, R., Wenzl, T., Jasti, P. R., Seefelder, W., 2013. Analytical approaches for MCPD esters and glycidyl esters in food and biological samples: A review and future perspectives. Food Additives & Contaminants: Part A, 30, 11–45.

Criado, M., Hemández-Martín, E., Otero, C., 2007. Optimized interesterification of virgin olive oil with a fully hydrogenated fat in a batch reactor: Effect of mass transfer limitations. Eur. J. Lipid Sci. Technol. 109, 474–485.

Dalgleish, D. G., 2006. Food emulsions: their structures and structure-forming properties. Food Hydrocolloids 20, 415–422.

Divinová, V., Svejkovská, B., Novotný, O., Velíšek, J., 2004. Survey of 3-chloropropane-1,2-diol and its precursors in foods in the Czech Republic. Czech J. Food Sci. 22, 230–234.

Doležal, M., Chaloupská, M., Divinová, V., Svejkovská, B., Velíšek, J., 2005. Occurrence of 3-chloropropane-1,2-diol and its esters in coffee. Eur. Food Res. Technol. 221, 221–225.

Driscoll, D. F., Giampietro, K., Wichelhaus, D. P., Peterss, H., Nehne Niemann, W., Britrian, B. R., 2001. Physicochemical stability assessments on lipid emulsions of varying oil composition. Clin. Nutr. 20, 151–157.

EC, 2001. European Commission Regulation No. 466/2001. Setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Communities L77/1, 16 March. Office for Official Publications of the European Communities, Luxembourg.

EFSA, 2008. Statement of the Scientific Panel on Contaminants in the Food chain (CONTAM) on a request from the European Commission related to 3-MCPD esters. Parma: European Food Safety Authority.

Fomuso, L.B., Akoh, C.C., 1997. Enzymatic modification of triolein: Incorporation of caproic and butyric acids to produce reduced-calorie structured lipids. J. Am. Oil Chem. Soc., 74, 269–272.

Flickinger, B. D., Matsuo, N., 2003. Nutritional characteristics of DAG oil. Lipids, 38, 129–132.

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 Sci. Technol. 42, 1751–1754.

Gamboa, O. W. D., Gioielli, L. A., 2006. Crystallization behavior of structured lipids produced from palm kernel fat and fish oil. Quimica Nova, 29, 646–653.

Hamlet, C. G., Jayaratne, S. M., and 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, 15–21.

Hamlet, C. G., Sadd, P. A., 2004. Chloropropanols and their esters in cereal products. Czech J. Food Sci. 22, 259–262.

Hsieh, H., Chen, J., Giridhar, R., Wu, W., 2005. Synthesis of mixed esters of ascorbic acid using methyl esters of palm and soybean oils. Prep. Biochem. Biotechn. 35, 113–118.

Indexmundi. com., 2013. "Indonesia Palm Oil Production by Year" & "Malaysia Palm Oil Production by Year". http://www.indexmundi.com/agriculture/?country=id&commodity=palm-oil&graph=production & http://www.indexmundi.com/agriculture/? country=my&commodity=palm-oil&graph=production (accessed 15 September 2014).

JECFA, 2001. Joint FAO/WHO Expert Committee on Food Additives, Fifty-seventh meeting, Rome, 5–14 June 2001.

Kaewthong, W., Sirisansaneeyakul, S., Prasertsan, P., H-Kittikun, A., 2005. Continuous production of monoacylglycerols by glycerolysis of palm olein with immobilized lipase. Proc. Biochem. 40, 1525–1530.

Lai, O. M., Low, C. T., Akoh, C. C., 2005. Lipase-catalyzed acidolysis of palm olein and caprylic acid in a continuous bench-scale packed bed bioreactor. Food Chem. 92, 527–533.

Lee, Y.-J., Lee, K.-T., 2009. Development and characterization of trans free margarine stock from lipase-catalyzed interesterification of avocado and palm oils. Korean J. Food Sci. Technol. 41, 231–237.

Lim, C. Y., 8 September 2014. Addressing palm oil concerns, The Star, Malaysia.

Lo, S. K., Baharin, B. S., Tan, C. P., Lai, O. M., 2004. Diacylglycerols from palm oil deodoriser distillate. part 2 - physical and chemical characterisation. Food Sci. Technol. Int. 10, 157–161.

Long, K., Zubir, I., Hussin, A. B., Idris, N., Ghazali, H. M., Lai, O. M., 2003. Effect of enzymatic transesterification with flaxseed oil on the high-melting glycerides of palm stearin and palm olein. J. Am. Oil Chem. Soc. 80, 133–137.

Low, C. T., Mohamad, R., Tan, C. P., Long, K., Ismail, R., Lo, S. K., Lai, O. M., 2007. Lipase-catalyzed production of medium-chain triacylglycerols from palm kernel oil distillate: Optimization using response surface methodology. Eur. J. Lipid Sci. Technol. 109, 107–119.

Lumor, S. E., Akoh, C. C., 2005a. Enzymatic incorporation of stearic acid into a blend of palm olein and palm kernel oil: Optimization by response surface methodology. J. Am. Oil Chem. Soc. 82, 421–426.

Lumor, S. E., Akoh, C. C., 2005b. Incorporation of γ-linolenic and linoleic acids into a palm kernel oil/palm olein blend. Eur. J. Lipid Sci. Technol. 107, 447–454.

Martínez, I., Angustias Riscardo, M., Franco, J., 2007. Effect of salt content on the rheological properties of salad dressing-type emulsions stabilized by emulsifier blends. J. Food Eng. 80, 1272–1281.

MPOB (Malaysian Palm Oil Board), 2013. Malaysian Palm Oil Statistics. Economics and industry development, division of Malaysian Palm Oil Board. Selangor, Malaysia.

Nagachinta, S., Akoh, C.C., 2012. Enrichment of palm olein with long chain polyunsaturated fatty acids by enzymatic acidolysis. LWT - Food Sci. Technol. 46, 29–35.

Nandi, S., Gangopadhyay, S., Ghosh, S., 2005. Production of medium chain glycerides from coconut and palm kernel fatty acid distillates by lipase-catalyzed reactions. Enzyme Microb. Technol. 36, 725–728.

Ng, S. P., Lai, O. M., Abas, F., Lim, H. K., Tan, C. P. 2014. Stability of a concentrated oil-in-water emulsion model prepared using palm olein-based diacylglycerol/virgin coconut oil blends: Effects of the rheological properties, droplet size distribution and microstructure. Food Res. Int. 64, 919–930.

Nor Haryati I.B., Che Man, Y.B., Tan, C.P., Nor Aini, I., 2005. Monitoring peroxide value in oxidized emulsions by Fourier transform infrared spectroscopy. Eur. J. Lipid Sci. Technol. 107, 886–895.

Nor Hayati, I., Che Man, Y.B., Tan, C.P., Nor Aini, I., 2007. Stability and rheology of concentrated o/w emulsions based on soybean oil/palm kernel olein blends. Food Res. Int. 40, 1051–1061.

Nor Hayati, I., Che Man, Y.B., Tan, C.P., Nor Aini, I., 2009a. Physicochemical characteristics of soybean oil, palm kernel olein and their binary blends. Int. J. Food Sc. Technol. 44, 152–161.

Nor Hayati, I., Che Man, Y.B., Tan, C.P., Nor Aini, I., 2009b. Thermal behavior of concentrated oil-in-water emulsions based on soybean oil and palm kernel olein blends. Food Res. Int. 42, 1223–1232.

Osório, N. M., Gusmão, J. H., Da Fonseca, M. M., Ferreira-Dias, S., 2005. Lipase-catalysed interesterification of palm stearin with soybean oil in a continuous fluidised-bed reactor. Eur. J. Lipid Sci. Technol. 107, 455–463.

Pande, G., Akoh, C.C., 2013. Enzymatic synthesis of trans-free structured margarine fat analogs with high stearate soybean oil and palm stearin and their characterization. LWT - Food Sci. Technol. 50, 232–239.

Pande, G., Akoh, C.C., Shewfelt, R.L., 2013. Utilization of enzymatically interesterified cottonseed oil and palm stearin-based structured lipid in the production of trans-free margarine. Biocatalysis Agri. Biotechnol. 2, 76–84.

Purseglove, J. W., 1985. Tropical Crops–Monocotyledons. Longman, London.

Ramírez Fajardo, A., Akoh, C. C., Lai, O. M., 2003. Lipase-catalyzed incorporation of n-3 PUFA into palm oil. J. Am. Oil Chem. Soc. 80, 1197–1200.

Saad, B., Ling, C. W., Jab, M. S., Lim, B. P., Ali, A. S. M., Wai, W. T., Saleh, M. I., 2006. Determination of free fatty acids in palm oil samples using non-aqueous flow injection titrimetric method. Food Chem. 102, 1407–1414.

Saberi, A.H., Lai, O.M., Miskandar, M.S., 2012. Melting and solidification properties of palm-based diacylglycerol, palm kernel olein, and sunflower oil in the preparation of palm-based diacylglycerol-enriched soft tub margarine. Food Bioproc. Technol. 5, 1674–1685.

Shamel, M. M., Ramachandran, K. B., Hasan, M., Al-Zuhair, S., 2007. Hydrolysis of palm and olive oils by immobilised lipase using hollow fibre reactor. Biochem. Eng. J. 34, 228–235.

Shimada, A., Ohashi, K., 2003. Interfacial and emulsfying properties of diacylglycerol. Food Sci. Technol. Res. 9, 142–147.

Siew, W. L., 2004. Chemical and physical characteristics of palm and kernel oils and their crystallization behavior. In Proceeding of 24th Palm Oil Familiarization Programme, pp. 81–103.

Siew, W. L., Kien, Y. C., Wai, L. T., 2007. Physical properties of lipase-catalyzed interesterification of palm stearin with canola oil blends. Eur. J. Lipid Sci. Technol. 109, 97–106.

Sime Darby, 2014). Palm Oil Facts & Figures. pp. 1–8.

Tan, C.H., Ghazali, H.M., Kuntom, A., Tan, C.P., Ariffin, A.A., 2009. Extraction and physicochemical properties of low free fatty acid crude palm oil. Food Chem. 113, 645–650.

Tan, Y. A., 1994. Analytical Techniques in Palm Oil and Palm Kernel Oil Specifications. In: Ariffin, A., Basri, M. N. H., Ahmad, M. J., Othman, R., Minal, J., Jaais, M. R. M. (Eds.), Selected Readings on Palm Oil and its Uses. Malaysia: Palm Oil Research Institute of Malaysia, pp. 78–90.

Tüter, M., Aksoy, H. A., 2005. Enzymatic glycerolysis of palm and palm kernel oils. Chem. Eng. Comm. 192, 14–17.

Vijaya, S., Ravi Menon, N., Helmi, S., Choo, Y.M., 2013. The development of a residual oil recovery system to increase the revenue of a palm oil mill. J. Oil Palm Res. 25, 116–122.

Wongsakul, S., Prasertsan, P., Bornscheuer, U. T., H-Kittikun, A., 2003. Synthesis of 2-monoglycerides by alcoholysis of palm oil and tuna oil using immobilized lipases. Eur. J. Lipid Sci. Technol. 105, 68–73.

You, L. L., Baharin, B. S., 2006. Effects of enzymatic hydrolysis on crude palm olein by lipase from *Candida rugosa*. Journal of Food Lipids, 13, 73–87.

Zelinková, Z., Svejkovská, B., Velíšek, J., Doležal, M., 2006. Fatty acids esters of 3-chloropropane-1, 2-diol in edible oils. Food Additives & Contaminants 23, 1290–1298.

Zelinková, Z., Doležal, M., Velíšek, J., 2009a. Occurrence of 3-chloropropane-1,2-diol fatty acid esters in infant and baby foods. Eur. Food Res. Technol. 228, 571–578.

Zelinková, Z., Doležal, M., Velíšek, J., 2009b. 3-Chloropropane-l,2-diol fatty acid esters in potato products. Czech J. Food Sci. 27, S421–S424.

Zhu, X.M., Hu, J.N., Xue, C.L., Lee, J.H., Shin, J.A., Hong, S. T., Sung, C. K., Lee, K. T., 2012. Physiochemical and oxidative stability of interesterified structured lipid for soft margarine fat containing Δ5-UPIFAs. Food Chem. 131, 533–540.

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 Chem. 135, 799–805.

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. J. Agric. Food Chem. 61, 3341–3349.