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...
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°C. Palm fruit bunches are first treated in a sterilizer where saturated steam at a pressure of 3 kg/cm² and a temperature of 140°C 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°C 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°C for 12.8h. 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

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

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


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

<table>
<thead>
<tr>
<th>Year</th>
<th>Malaysia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>0.64</td>
</tr>
<tr>
<td>1980</td>
<td>1.02</td>
</tr>
<tr>
<td>1985</td>
<td>1.48</td>
</tr>
<tr>
<td>1990</td>
<td>2.03</td>
</tr>
<tr>
<td>1995</td>
<td>2.54</td>
</tr>
<tr>
<td>2000</td>
<td>3.37</td>
</tr>
<tr>
<td>2005</td>
<td>4.05</td>
</tr>
<tr>
<td>2010</td>
<td>4.85</td>
</tr>
<tr>
<td>2013</td>
<td>5.23</td>
</tr>
</tbody>
</table>

(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 °C during deodorization, but a higher temperature (270 °C) 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-parts 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°C 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, mayonnaise, 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 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°C 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.

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


