Journal of Oil Palm Research Vol.30 (2) June 2018 p. 163 – 195
DOI: https://doi.org/10.21894/jopr.2018.0030

OIL PALM ECONOMIC PERFORMANCE IN MALAYSIA AND R&D PROGRESS IN 2017

KUSHAIRI, A*; SOH KHEANG LOH*; AZMAN, I*; ELINA HISHAMUDDIN*; MEILINA ONG-ABDULLAH*; ZANAL BIDIN MOHD NOOR IZUDDIN*; RAZMAH, G *; SHAMALA SUNDRAM* and GHULAM KADIR AHMAD PARVEEZ*

ABSTRACT

*Oil palm (*Elaeis guineensis *Jacq.) has emerged as a major economic crop feeding the world today. This article aims to capture the more recent progress made by the oil palm industry and to discuss the possible path research and development will take in the coming years. In 2017, palm oil and palm kernel oil production recorded close to one-third (75.17 million tonnes) of world total oils and fats production from a planted area of 19.04 million hectares, mainly from Indonesia and Malaysia. Malaysian palm oil alone fetched RM 46.12 billion export revenue from its India and European Union markets. The continuous growth of the industry is made possible through implementation of key strategies covering the whole process chain, from upstream to downstream. Intensified mechanisation, integrated pest and* Ganoderma *management, advanced breeding and biotechnology as well as good agricultural practices help boost oil palm yields for both plantations and smallholdings. In the palm oil milling sector, focus such as by-products valorisation, biogas (productivity, trapping and utilisation as a form of energy) and wastewater management,* i.e. *palm oil mill effluent for final discharge compliance ensures that the industry meets its sustainable goals. Palm oil is generally used for edible purpose, however about 20% goes into higher value non-food applications such as palm biodiesel. The beneficial nutritional aspects of palm oil are evident based on its positional distribution and fatty acids composition, while its quality enhanced via technology integration/mitigation and analytical elucidations. Facing strong competition from petrochemicals, palm-based oleochemicals are strategically aimed at producing value-added products for niche and new markets. It is apparent that synergising conventional and disruptive technologies at every level of the palm oil supply chain is desirable and essential to thrust the industry forward. As a commodity, palm oil has not only emerged as an important food source, but has proven to be effectively utilised for feed, fuels and chemicals, to name a few, in developing a sustainable and balanced circular economy.*

Keywords: palm oil, oil palm biomass, economic performance, productivity, bioenergy, food and nutrition, oleochemicals.

Date received: 15 May 2018; **Sent for revision:** 17 May 2018; **Received in final form:** 12 June 2018; **Accepted:** 13 June 2018.

INTRODUCTION

The world's major oils and fats production, to name a few, in their descending order are: palm oil (PO) (67.92 million tonnes), soyabean oil (53.94 million tonnes), rapeseed oil (25.32 million tonnes), sunflower oil (19.00 million tonnes), palm kernel oil (PKO) (7.25 million tonnes), corn oil (4.31 million tonnes), cottonseed oil (4.21 million tonnes), groundnut oil (4.14 million tonnes), olive oil (2.99 million tonnes), coconut oil (2.44 million tonnes), *etc*. amounting to 221.26 million tonnes in 2017

* Malaysian Palm Oil Board, 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia.
E-mail: kushairi@mpob.gov.my

(Oil World, 2018). PO and PKO contribute 34% or about one-third of world oils and fats production, signifying the importance and high productivity of oil palm in supporting world population, covering a total planted area of 19.04 million hectares, *i.e.* 0.36% of world agricultural land. Major world producers of PO are Indonesia, Malaysia, Thailand, Colombia and Nigeria. Indonesia is the world first major producer and exporter of PO followed by Malaysia. Meanwhile, world major importers of PO are India, European Union (EU), China, Pakistan, USA, Bangladesh, Nigeria, Philippines, *etc.*

In Malaysia, the oil palm industry plays an important role in the agricultural and economic development of the country. The successful commercial planting of the exotic *Elaeis guineensis* Jacq. in 1917 in Tenammaram Estate, Kuala Selangor has brought about substantial social and economic prosperity for Malaysia. The industry continues to contribute significantly to gross domestic product (GDP), gross national income (GNI), foreign exchange and employment. This article provides an insight on the performance of the oil palm industry as well as the research and development (R&D) undertaken for the year 2017. Specifically, the performance of the Malaysian oil palm industry will be discussed first, next the progress made in R&D worldwide across the whole process chain and lastly areas for improvement and future direction for continued growth of the industry in the coming years.

METHOD

A desktop study was conducted to mass review R&D and commercialisation aspects of the oil palm industry covering upstream - biology, biotechnology, mechanisation, integration and extension; midstream - engineering and processing, biomass and bioenergy and downstream - nutrition and food, oleochemicals. Primary data for economic performance assessment were gathered by the Malaysian Palm Oil Board (MPOB) via regular data collection from producers, manufacturers/ processors, dealers and other related parties of the oil palm industry. The relevant data were collected through online systems such as e-submission (for planters), e-kilang (millers), e-peniaga (dealers), e-oleo (oleochemical), e-registration (prices) and e-QC (import and export of oil palm products). Most of the data were collected on monthly and yearly basis. For instance, data through e-submission were collected on monthly basis and comprised total planted area (mature and immature areas), harvested area and fresh fruit bunches (FFB) production. Besides, data such as volume and value of exports of PO products were also sourced from the Department of Statistics, Malaysia.

PERFORMANCE OF MALAYSIAN OIL PALM INDUSTRY

The Malaysian oil palm planted area has increased from 5.74 million hectares in 2016 to 5.81 million hectares in 2017 (MPOB, 2018) (*Figure 1*). Total planted areas in Sarawak, Sabah and Peninsular Malaysia were 1.56 million hectares (26.8%), 1.55 million hectares (26.6%) and 2.70 million hectares (46.6%), respectively. The majority of the planted area was owned by private estates (~61%) while those with government schemes such as Federal Land Development Authority (Felda), Federal Land Consolidation and Rehabilitation Authority (Felcra) and Rubber Industry Smallholders Development Authority (RISDA), 16.1%; state schemes/ government agencies, 6% and independent smallholders, 16.9% (*Table 1*). The smallholders occupied 2.27 million hectares, *i.e.* 39% from the total planted areas in 2017. An increasing trend was also observed for independent smallholders (ISH) accounting to 0.98 million hectares.

The average FFB yield for 2017 increased by 12.5% to 17.89 t ha^{-1} as against 15.91 t ha^{-1} achieved in 2016 due to recovery from the impact of the *El Nino* phenomenon a year earlier. *Figure 1* shows a 27-year trend in national FFB yield with a downtrend tendency. Seemingly, FFB yield growth was noticeably recorded throughout 2017 except in June (*Figure 2*) compared to the previous year. The yield in June 2017, as recorded, was lower than in June 2016 as harvesters were unavailable due to Aidilfitri festive season.

The PO milling sector has developed tremendously with an increased number of operating palm oil mills over time. In 1990, there were only 261 palm oil mills in operation with a total processing capacity of 42.87 million tonnes FFB per year. Two decades later, the number had increased by 61.3% to 421 mills with a total FFB processing capacity of 97.38 million tonnes per year. The growth of oil palm planted area directly contributes to the increase in palm oil mills. In 2017, there were 454 operating mills in Malaysia with a total processing capacity of 112.19 million tonnes per year (*Table 2*).

Oil extraction rate (OER) refers to the weight percentage of PO physically recovered from a known weight of FFB processed in palm oil mills. The average OER declined to 19.7% compared to 20.2% in the previous year, mainly due to lower quality of FFB processed in palm oil mills. On average, almost all months in 2017 recorded lower yield against their corresponding months in 2016 except for May and June (*Figure 3*). The low OER for May and June 2016 was due to prolonged dry weather arising from *El Nino* effect causing inferior FFB quality. The OER in Peninsular Malaysia, Sabah and Sarawak declined by 2.8%, 2.4% and 0.2% to 19.21%, 20.60% and 19.98%, respectively.

TABLE 1. DISTRIBUTION OF OIL PALM PLANTED AREA BY CATEGORY IN MALAYSIA (2016-2017)

Category	Hectarage			
	2017		2016	
	ha	%	ha	%
Private estates	3 543 429	61.0	3 508 554	61.2
Government schemes	940 326	16.1	951 169	16.5
State schemes/government agencies	347 632	6.0	344 314	6.0
Independent smallholders	979 758	16.9	933 948	16.3
Total	5 811 145	100.0	5 737 985	100.0

Source: MPOB (2018).

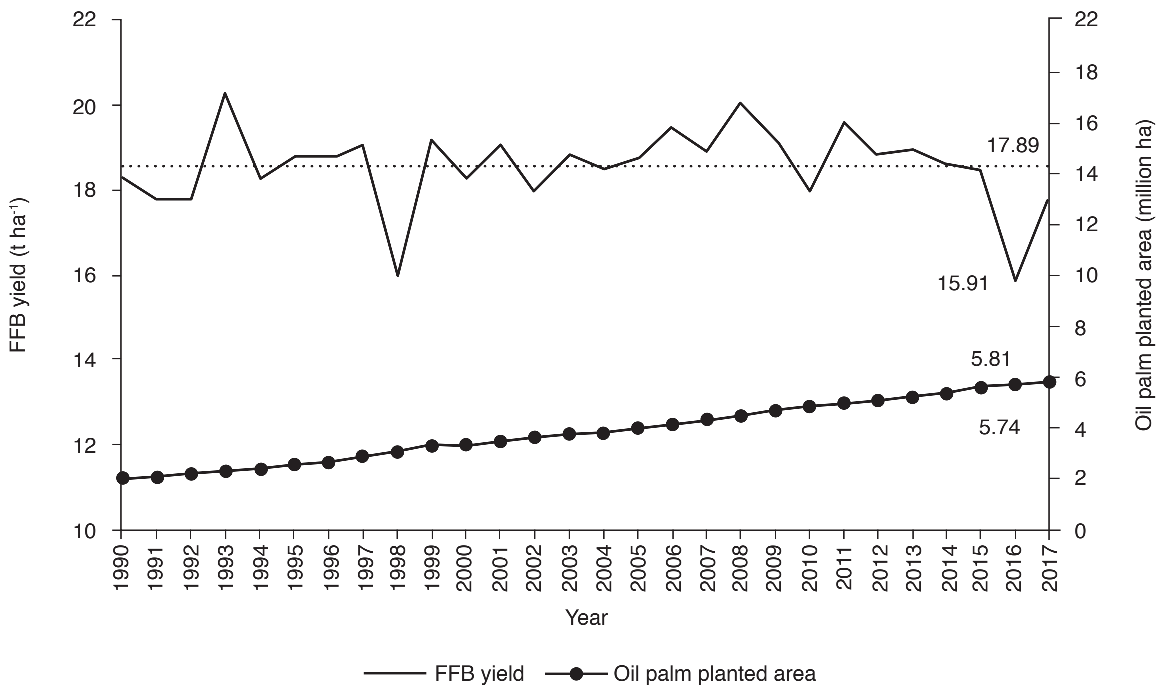

Figure 1. Fresh fruit bunches (FFB) average yield performance (1990-2017).

TABLE 2. NUMBER OF PALM OIL MILLS, REFINERIES, KERNEL CRUSHERS AND OLEOCHEMICAL PLANTS AND THEIR CAPACITIES IN MALAYSIA IN 2017

Facility	No.	Processing capacity (t yr^{-1})
Palm oil mill	454	112 187 800
Palm oil refinery	53	27 328 200
Kernel crusher	45	7 269 700
Oleochemical plant	19	2 668 929

Source: MPOB (2018).

Crude palm oil (CPO) production in 2017 increased by 15.0% to 19.92 million tonnes compared to 17.32 million tonnes in the previous year. The increase was due to higher FFB processed, up by 17.7% arising from 12.4% higher FFB yield. CPO production in Peninsular Malaysia, Sabah and Sarawak increased by 19.0%, 7.6% and 15.1% to 10.58 million tonnes, 5.22 million tonnes and 4.13 million tonnes, respectively.

As at December 2017, 53 palm oil refineries were in operation with a total annual refining capacity of 27.33 million tonnes. Of these, 35 refineries with a total processing capacity of 15.48 million tonnes per year were located in Peninsular Malaysia whereas 12 were in Sabah and 6 in Sarawak with a total processing capacity of 8.74 million tonnes and 3.12 million tonnes, respectively (*Table 2*).

In 2017, a total of 17.64 million tonnes of CPO and crude PKO were processed by the refineries, *i.e.* an increase of 13.1% compared to the previous year. CPO accounted for 16.18 million tonnes (91.7% of the total feedstock processed) and crude PKO at 1.46 million tonnes (8.3%). The refining utilisation rate increased by 8.7% to 64.5% compared to the previous year.

There were 45 palm kernel crushers in operation in 2017 with a total annual crushing capacity of 7.27 million tonnes (*Table 2*). A total of 4.97 million tonnes of palm kernel were crushed, an increase of 16.7% as against the previous year. The kernel crushing

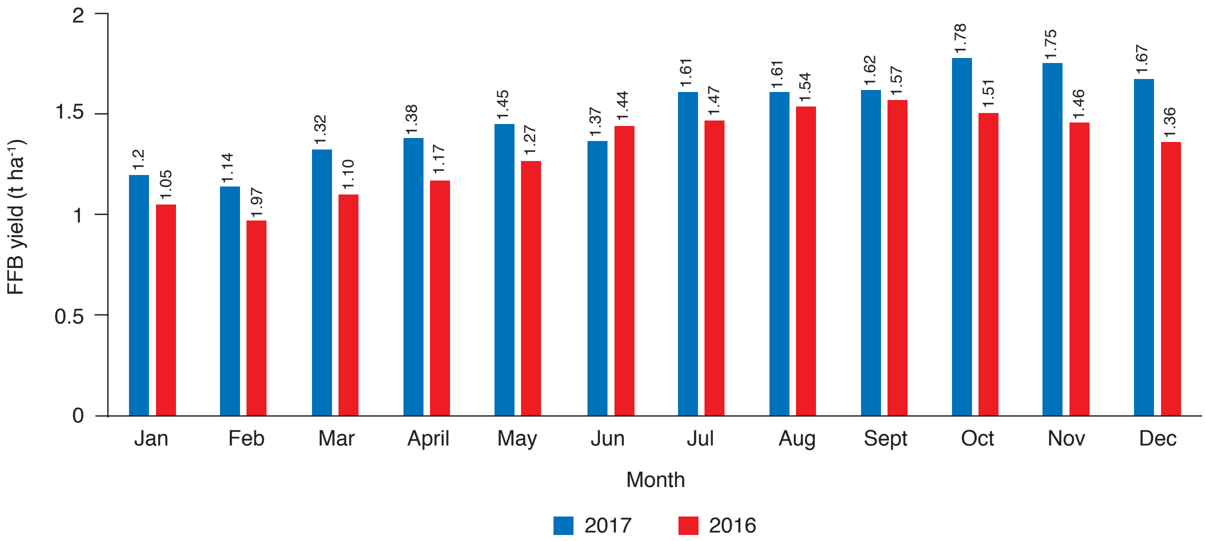

Figure 2. Fresh fruit bunches (FFB) monthly yield (2017 vs. *2016).*

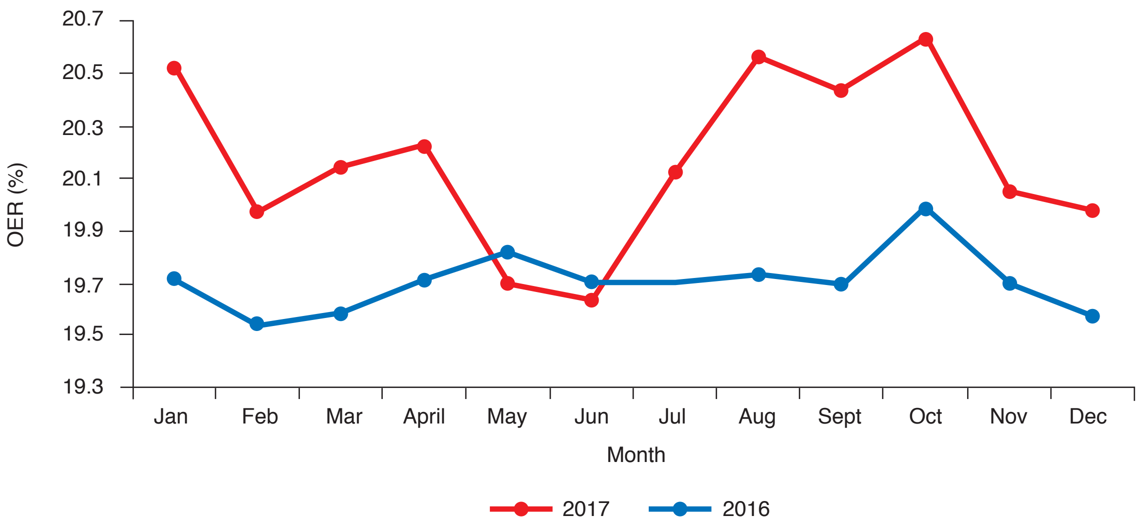

Figure 3. Oil extraction rate (OER) monthly performance (2017 vs. *2016).*

utilisation rate increased to 65.2% from 59.5% recorded in the previous year.

A total of 19 oleochemical plants were in operation throughout Malaysia, with an annual processing capacity of 2.67 million tonnes (*Table* 2). The utilisation rate of oleochemical processing capacity in 2017 increased to 94.9% from 85.2% recorded in the previous year, in line with higher volume of PO and PKO processed.

Due to higher export volume and better prices of oil palm products, the total export revenue from oil palm products in 2017 increased sharply by 14.62% to RM 77.85 billion compared to RM 67.92 billion achieved in 2016 (MPOB, 2017). PO export earnings alone increased by 11.3% to RM 46.12 billion against RM 41.44 billion in 2016. PO export volume in 2017 increased by 3.2% to 16.56 million tonnes (*Table* 3) compared to 2016 due to higher demand, especially from Saudi Arabia, Iran, Pakistan and the Philippines.

India remained its position as the largest export market for the Malaysian PO in 2017 even though its total import (2.03 million tonnes) declined by 28.2% compared to 2.83 million tonnes in 2016, due to competition from Indonesia and higher import of sunflower oil. The second largest export market was the EU with 1.99 million tonnes or 12.0% of total PO exports, followed by China 1.92 million tonnes (11.6%), Pakistan 1.02 million tonnes (6.1%), the Philippines 0.75 million tonnes (4.5%), Turkey 0.68 million tonnes (4.1%) and Vietnam 0.63 million tonnes (3.8%). These combined seven markets accounted for 9.02 million tonnes or 54.5% of the total Malaysian PO exports in 2017. The slight decline (3.3%) in export of PO to the EU in 2017 was due to higher import of PO from elsewhere and intake of

TABLE 3. SUMMARY ON THE PERFORMANCE OF THE MALAYSIAN OIL PALM INDUSTRY, 2017 AND 2016

	2017 (a)	2016 (b)	Difference (a-b) Volume/ value	%
Planted area (ha)				
Malaysia	5 811 145	5 737 985	73 160	1.3
Peninsular Malaysia	2 708 413	2 679 502	28 911	1.1
Sabah	1 546 904	1 551 714	-4 810	-0.3
Sarawak	1 555 828	1 506 769	49 059	3.3
Crude palm oil production (t)				
Malaysia	19 919 331	17 319 177	2 600 154	15.0
Peninsular Malaysia	10 575 920	8 886 638	1 689 282	19.0
Sabah	5 215 345	4 847 253	368 092	7.6
Sarawak	4 128 066	3 585 286	542 780	15.1
Closing stocks (t)				
Crude palm oil	1 669 196	877 082	792 114	90.3
Processed palm oil	1 062 897	789 591	273 306	34.6
Total palm oil stocks (t)	2 732 093	1 666 673	1 065 420	63.9
Export (t)				
Palm oil	16 559 957	16 045 957	514 000	3.2
Palm kernel oil	967 465	923 097	44 369	4.8
Palm kernel cake	2 206 657	2 213 847	-7 190	-0.3
Oleochemicals	2 774 235	2 757 756	16 479	0.6
Biodiesel	235 291	83 581	151 711	2.8 folds
Finished products	406 270	489 071	-82 800	-16.9
Other palm products	824 650	780 832	43 818	5.6
Total exports (t)	23 974 526	23 294 140	680 386	2.9
Export revenue (RM million)				
Palm oil	46 124.76	41 442.91	4 681.85	11.3
Palm kernel oil	5 774.28	5 095.81	678.48	13.3
Palm kernel cake	927.21	838.36	88.85	10.6
Oleochemicals	20 395.25	16 838.24	3 557.01	21.1
Other palm products	4 626.88	3 706.84	920.04	24.8
Total revenue (RM million)	77 848.39	67 922.16	9 926.22	14.6
Import (t)				
Palm oil	556 095	415 414	140 681	33.9
Palm kernel oil	182 106	143 436	38 671	27.0
Price (RM t^{-1})				
Fresh fruit bunches (mill gate)	606.00	594.00	12.00	2.0
Crude palm oil (local delivered)	2 783.00	2 653.00	130.00	4.9
Palm kernel (ex-mill)	2 536.00	2 611.00	-75.00	-2.9
Crude palm kernel oil (local delivered)	5 325.00	5 492.50	-167.50	-3.0
RBD palm oil (FOB)	2 880.00	2 710.50	169.50	6.3
RBD palm olein (FOB)	2 953.50	2 769.50	184.00	6.6
RBD palm stearin (FOB)	2 799.50	2 650.50	149.00	5.6
Palm fatty acid distillate (FOB)	2 733.00	2 462.50	270.50	11.0
Oil extraction rate (%)				
Malaysia	19.72	20.18	-0.46	-2.3
Peninsular Malaysia	19.21	19.76	-0.55	-2.8
Sabah	20.60	21.11	-0.51	-2.4
Sarawak	19.98	20.02	-0.04	-0.2
Fresh fruit bunches yield (t ha^{-1})				
Malaysia	17.89	15.91	1.98	12.4
Peninsular Malaysia	18.70	15.77	2.93	18.6
Sabah	18.35	17.10	1.25	7.3
Sarawak	16.13	14.86	1.27	8.5

Note: FFB - fresh fruit bunches. RBD - refined, bleached and deodourised. FOB - freight on board.
Source: MPOB (2017); Department of Statistics, Malaysia.

sunflower oil. The increases by 1.9% to China and 13.8% to Vietnam, and 15.5% to Pakistan and 3.4% to Turkey, were due to lower import of soyabean and rapeseed, respectively for crushing. The Philippines recorded 20.3% import increase due to lower supply of domestic coconut oil.

PKO exports also increased by 4.8% to 0.97 million tonnes (*Table 3*) in 2017 due to higher demand from China, Brazil and India. As in the previous year, the EU was still the major export market for PKO with 0.25 million tonnes (26.0% of total exports), followed by China 0.17 million tonnes (17.5%) and Turkey 0.08 million tonnes (8.0%). Besides, exports of palm-based oleochemical products increased slightly by 0.6% to 2.77 million tonnes in 2017 due to stronger demand from China and USA. Nevertheless, the EU maintained as the major importer with 0.45 million tonnes (16.2% of total exports), followed by China, 0.44 million tonnes (15.9%); USA, 0.31 million tonnes (11.1%) and Japan, 0.23 million tonnes (8.5%). The major palm-based oleochemical products exported in 2017 were fatty acids at 0.99 million tonnes (35.7%); fatty alcohol, 0.58 million tonnes (20.9%); methyl ester, 0.44 million tonnes (15.8%); glycerine, 0.40 million tonnes (14.5%) and soap noodles, 0.34 million tonnes (12.1%).

Exports of palm kernel cake (PKC) in 2017 declined slightly by 0.3% to 2.207 million tonnes (*Table 3*) due to lower demand from the EU (reduced by 28.6%). New Zealand was the largest importer with 0.65 million tonnes (29.4% of total exports) followed by the EU, 0.48 million tonnes (21.9%); South Korea, 0.34 million tonnes (15.4%); Pakistan, 0.30 million tonnes (13.6%) and China, 0.17 million tonnes (7.6%). All in all, these countries imported 87.9% of Malaysia's PKC in 2017. Palm biodiesel exports were up by two-fold from 83 581 t in 2016 to 235 291 t in 2017. *Table 3* summarises the performance of the Malaysian oil palm industry in 2017 (MPOB, 2017).

R&D FOCUS AREAS IN 2017

Increased Productivity

Changes in upstream. Among the transformative research that has a clear transcending effect on oil palm productivity is mechanisation. The industry would benefit from mechanisation technologies to reduce the dependence on human labour and issues associated with labour shortage for oil palm harvesting. Mechanisation is also important to reduce time and energy. *Cantas*, a man-held motorised harvesting tool has significantly increased productivity while reducing labour dependency (Jelani *et al*., 2016). Oil palm loose fruit separating machine uses vibration and airstream to effectively separate thrash (98.9%) from loose fruits (Khalid and Shuib, 2017).

In line with utilisation of renewable energy sources as part of sustainable agriculture effort, an integrated solar photovoltaic electric vehicle (EV) in oil palm farm mechanisation was developed (Azwan *et al*., 2017). Spraying herbicide using EV was more cost-effective compared to traditional knapsack spraying system apart from being a greener technology which could be advantageous for operational cost reduction, productivity increase and greenhouse gas emissions mitigation. Improved planting materials with specific altered phenotypic characteristics such as low stem height and long stalk would facilitate deployment of mechanisation technologies (Kushairi *et al*., 2017).

Agriculture through large scale mono-cropping deliberately introduces changes in the existing environment exposing the crop to serious attacks by pests and diseases. Among the pest intrusions, bagworms, known as the leaf-eating pest, remain the most economically important in Malaysia (Norman and Basri, 2007). Research has been dedicated to controlling this pest using *Bacillus thuringiensis* (Bt) and other forms of pheromone trapping through integrated pest management (Mohd Najib *et al*., 2017; Noorhazwani *et al*., 2017). These technologies provide a sustainable approach in addressing and managing the issue.

Oil palm cultivation spreads across four continents and diseases affecting the crop are confined according to the region where it is planted (Sundram and Intan-Nur, 2017). In Southeast Asia, *Ganoderma*, once known to be an aging palms' problem, has gradually become a serious threat to the oil palm industry. The white rot fungus infects and gradually cripples the productive lifespan of the palm if left untreated. The success in reducing the disease incidences largely depends on the implementation of integrated *Ganoderma* management that combines cultural practices coupled with biological and chemical controls (Idris *et al*., 2016) along with reliable early detection tools. Precision agriculture for the early detection of *Ganoderma* will be the best way forward to assist in mitigating and managing the disease effectively. Early success of this technology has been realised through the studies of Izzuddin *et al*. (2017) and Ahmadi *et al*. (2017) detailing the potential use of the technology in field. Additionally, as a long-term strategy of controlling the disease through green technologies, we could envisage the potential use of various biocontrol agents in controlling the disease as part of the comprehensive integrated *Ganoderma* management strategy (Angel *et al*., 2017; Kamaruddin *et al*., 2017; Naidu *et al*., 2017).

Breeding oil palm for disease resistance has been an important goal with increasing setting up of in-house screening facilities for oil palm germplasm population. The successful identification of four *Ganoderma* resistance loci in oil palm provided an important milestone for the oil palm varieties selection with potential *Ganoderma* resistance (Tisné *et al*., 2017). This development will certainly set a new perspective in the screening process. Moving on with fundamental research, work by Mercière *et al*. (2017) through spatial autocorrelation further sparked the role of spore dispersal in the spread of the deadly disease. There is an absolute urgency in proving the role of spores as it involves the potential change of practices in estate to reduce the predisposing effect of spores.

A subtle change in climate has already influenced the FFB yield production. It is predicted that climate change may lead to the emergence of new pests and diseases (Sundram and Intan-Nur, 2017). Possibility exists for their increases with pathogen evolution and interaction with susceptible host. Bearing this in mind, a biosecurity alert took place four years ago following the catastrophic devastation of bud rot disease witnessed by the South American oil palm industry. This was due to the fact that the causal agent reported for the disease was also a local indigenous pathogen affecting other commodity crops in Malaysia; *Phytophthora palmivora*. Thus, various research activities were conducted to assess the susceptibility of local oil palm, resulting from negative pathogenicity on local palm (Intan-Nur *et al*., 2017). The findings increase the risk and place pressure in tightening the potential pathways that may introduce the pathogen through biosecurity. On the other hand, a new genetically different invasive haplotype of coconut rhinoceros beetle Guam (CRB-G) reported in Port Moresby, O'ahu and Honiara, is currently causing fear among the coconut and oil palm growers (Marshall *et al*., 2017). What is even more alarming is the fact that the pest cannot be controlled by its natural known control agent, *Oryctes rhinoceros nudivirus* (OrNV). This calls for a vigilant improvement of the existing biosecurity policies to avoid unnecessary introduction of the pest to this part of the world.

The rapid expansion of oil palm cultivation in Southeast Asia in the last few decades also witnessed the conversion of marginal land areas, such as peat for oil palm cultivation. This has clearly sparked international attention considering the fact that the largest biological carbon sink reservoir in the world is being disturbed. The issue continued to receive international scrutiny and backlashing by scientific communities and non-governmental organisations questioning on the level of sustainability practices and its consequences to ecosystem and people. Although peat cultivation in Malaysia only comprises 13% with the remaining cultivated in mineral soil (Hashim *et al*., 2017), it is important to identify the downside of peat cultivation and knowledge gaps. Realising the significance in addressing the above, a systematic review by Dislich *et al*. (2017) highlighting the impact of oil palm expansion against forest (as reference) identified 14 critical ecosystem functions among which 11 showing a net decrease. The study also listed research gaps, mitigation options and recommendations on the simultaneous improvement of one or more ecosystems. Additionally, some case studies have also reported effects of peat cultivation on biodiversity and impact of climate change such as *El Nino* (Itoh *et al*., 2017; Qie *et al*., 2017; Siti *et al*., 2017). Malaysia has been championing research on increasing yield and reducing expansion to new lands which reinforces its role in protecting and preserving the existing peat ecosystem and therefore has taken steps to improve the converted peat cultivation through proven recommendations (*e.g.* drainage and upstream hydrology). Aside from addressing the public perception on oil palm planted on peat (Hashim *et al*., 2017), more studies are required on investigating potential greenhouse gas emissions due to anthropogenic activities and peat conversion.

Biotechnological advancement. Essentially, crop yield improvement is the main thrust area for the agriculture sector and that includes the oil palm. Its urgency is further fuelled by the projected growth of global population to a staggering 9.7 billion by 2050, leading to a need to double global fat production to meet the additional caloric requirement. It is now common knowledge that to keep pace with this growing demand, the more sustainable alternative would be to increase productivity on existing planted areas, whilst being mindful of minimising the negative effects in the quest to achieve these goals (Ehrlich and Harte, 2015). In reality, agricultural production is experiencing lower yields due to climate disruption and crop quality is threatened by loss of pollinators and increasing atmospheric CO_2. Deterioration of soil health from erosion, salinisation and nutrient depletion as well as the limited water resource are the growing concerns of agriculture. Therefore, to effectively reduce pressure on land whilst increasing yields, a thorough understanding of factors influencing oil palm yields is required to determine the scope to increase productivity. In this aspect, yield gap analysis which is a tool commonly used to estimate the upper limit of productivity per hectare of the palm or its potential yield in a given condition to resolve yield-determining, yield-limiting, and yield-reducing factors of the oil palm. By closing the yield gaps, it is envisaged that global production will increase without further expansion of land (Woittiez *et al*., 2017).

Aside from addressing external factors to improve productivity, alternatively crop improvement can be achieved through breeding. However, conventional breeding especially for a perennial such as oil palm generally takes a long time (approximately 19 years per cycle of phenotypic selection) to realise any genetic gain per unit time and cost (Wong and Bernado, 2008). Therefore, if there are new and available technologies that can speed up breeding, this would put oil palm in better stead. The simulation exercise by Wong and Bernado (2008) highlighted the superiority of genome-wide or genomic selection over phenotypic or marker assisted recurrent selection (MARS) methods. The advantage of genomic selection (GS) lies in the fact that predictions of breeding and genotypic values are made based on the combination of marker and phenotypic data (and where available, pedigree information too). This helps to increase the genetic gain of complex traits per unit time and cost (Bhat *et al*., 2016). To date, reports on the application of GS on various crops have been on the rise. Recently, Kwong *et al*. (2017) demonstrated with exceptional accuracy the power of GS in selecting effective markers targeting desired traits in the oil palm. These markers were used to construct a predictive model associated to the desired trait from a training population with known genotypic and phenotypic information. This enables the genomic estimated breeding value (GEBV) to be determined for its subsequent use in selection of the best performing progenies. Similarly, the calculated GEBV can also be used to select for best parents. Besides GS, Genome-wide Association Studies (GWAS) has also been widely used in linking quantitative trait loci (QTL) to key agronomic traits which would lead to the identification of candidate genes associated to these traits (Cao *et al*., 2015; Maizura *et al*., 2017). Maizura *et al*. (2017) reported the first GWAS and GS study for a germplasm, in particular from Angola. Many studies have now shown that both GWAS and GS working in tandem have been effective in developing superior varieties (Minamikawa *et al*., 2017). This has motivated Li *et al*. (2017a) to develop an efficient unified model combining both methods as GWAS improves genomic prediction accuracy, while GS increases mapping precision and minimises the rate of false positives of GWAS.

Despite the increasing popularity of genome-wide screening, QTL mapping is still widely used. A recent paper by Tisné *et al*. (2017) revealed four loci identified as *Ganoderma* disease resistant by using a multi-parental population of oil palm. Incidentally, merger of both QTL mapping approach and GWAS had proven to be beneficial as QTL data was further improved (Sonah *et al*., 2014; He *et al*., 2017; Wen *et al*., 2017).

There have been huge developments in the 'omics' front of late other than genomics. The information generated from these other 'omics' approaches such as transcriptomics, epigenomics, proteomics, metabolomics and phenomics have provided the added enhancement towards improving crop performance and higher genetic gains (Emon, 2016). Teh *et al*. (2017) provided a very comprehensive review on the contribution of the 'omic'-es towards strategically improving yields in oil crops. The article stresses on the need to study beyond classical trait selection, *e.g.* oil biosynthesis and fruit development to name a few, but to expand into areas such as carbon assimilation, stress response, nutrient uptake and water use. Some examples of research that further add value to oil palm's 'big data' are Jin *et al*. (2017) on hybrid vigour, Tan *et al*. (2017a) for proteomics in tissue culture and Ho *et al*. (2017) on microRNA related to flowering. To deal with the 'data tsunami' from all these research efforts, good bioinformatics support is critical. In this aspect, Chan *et al*. (2017a) developed a pipeline for gene prediction for the oil palm which could also be a good resource for other related crops.

Recently, poor fruit set in oil palm has become more apparent in East Malaysia especially in peat areas. Seasonal bouts of poor (10%-20%) fruit set could be caused by the dwindling population of pollinating weevil due to excessive rain, absence of sufficient male flowers and infection with parasitic nematodes (Rao and Law, 1998). They recommended a minimum of two male palms per hectare in plantations with a high sex ratio in order to provide sufficient supply of pollen and maintain weevil populations. The article by Li *et al*. (2017b) is probably the first report whereby a molecular approach is taken to better understand the current situation. The gene *EgMYB4*, which is a transcription factor involved in methylchavicol production in flowers or better known as estragole, belonging to the phenylpropanoid pathway was identified. Phenylpropenes belong to a class of volatile organic compounds produced by plants to attract pollinators as well as for defence purposes. They share the same pathway with lignin, flavonoid, phenolic acid and stilbene production (Liu *et al*., 2015). It is suggested that *EgMYB4* restricts biosynthesis of lignin in oil palm flowers thus redirecting the carbon flux towards the phenylpropene pathway.

One of the areas where there is much anticipation in the years ahead is definitely genome editing. Interestingly, date palm researchers have openly acknowledged plans of applying clustered regularly interspaced short palindromic repeats or better known as CRISPR/Cas9 in their crop improvement programme. In their recent review, Sattar *et al*. (2017) are encouraged by the potential of this technology to be the way forward for date palm considering the limitations faced by the crop. This presents a good reference for its close cousins, the oil palm and coconut to follow suit. With the recent successful regeneration of oil palm from protoplasts (Masani *et al*., 2013), early evidence of gene transfer into oil palm protoplasts (Masani *et al*., 2014) and development in oil palm genome studies (Low *et al*., 2017), it was proposed that genome editing could be applied to oil palm to genetically improve oil palm more effectively than being carried out now using the genetic transformation methods (Subhi *et al*., 2017).

When addressing issues pertaining to climate change, developing planting materials that are able to weather these changes are crucial to safeguard the posterity and sustainability of the crop (Zulkifli *et al*., 2017a). One of the major traits that is being targeted is drought tolerance or water-use efficiency. Both Li *et al*. (2017c) and Hughes *et al*. (2017) reported that reduced stomatal density seems to confer improved drought tolerance without compromising yield in both wheat and barley, respectively. This would be a potential area for oil palm to explore.

Smallholders involvement. In Malaysia, two categories of oil palm smallholders, the ISH and organised smallholders, have played significant contribution to the oil palm industry. The main challenge of ISH is low productivity affecting their socio-economic situation. Over the last decade, the oil palm yield produced by ISH was always below the national average. For example, in 2017, the average yield for ISH was 17.19 t ha^{-1} which was slightly lower compared to the national average of 17.89 t ha^{-1} (MPOB, 2017). This lower yield was mainly due to lack of proper oil palm management. Besides good agricultural practices and fertiliser management, good planting materials is also the main factor influencing the potential FFB yield by smallholders. Selection of high quality oil palm seedlings for planting is a crucial part in the whole period of oil palm management activities. Establishing extension and support services for ISH is crucial, *e.g.* in Malaysia as one main activity since 1993. Recent relevant knowledge and technologies related to oil palm production have been disseminated to enhance the skills of ISH in oil palm management. Furthermore, adoption of any oil palm technologies, farm practices and oil palm production by ISH need to be monitored closely. Fatin *et al*. (2017) showed that current extension activities implemented are able to create awareness among smallholders in implementing good agricultural practices. The study also suggested that the current extension and monitoring programs should be continued.

Farm Book Record to monitor oil palm management activities by the ISH has been introduced to ease implementation of extension services. Although some smallholders have maintained the Farm Book Record, not all information required by the extension agents is recorded (Parthiban *et al*., 2017a). Most of the ISH provide inconsistent and inaccurate information, especially in actual production of FFB, thus hindering effective extension services by governmental bodies. Currently, no specific system is in place to capture records on FFB yields by ISH in Malaysia. Therefore, a new database system known as Oil Palm Smallholder Information Card was introduced in order to capture FFB transactions by smallholders (Partiban *et al*., 2017a). However, this system needs to be further improved for effective tracking of FFB yields and transactions by including an online web-based portal for data entry.

Assessment of level of knowledge of ISH on important oil palm management skills is crucial to gather sufficient information for planning effective and suitable training program for the smallholders. Parthiban *et al*. (2017b) conducted such assessment on Basal Stem Rot disease caused by the fungus *Ganoderma* and the control practices. It was found that majority of ISH are ignorant on the key oil palm disease, *Ganoderma*. Therefore, suitable training and courses are to be repeatedly conducted to enhance their skills in order to reduce infestation and spread of this disease. We anticipate more such similar studies to be conducted relating to important oil palm management skills.

Following initiatives to increase the income of oil palm smallholders, the government encouraged smallholders to be involved in cooperative activities by establishing Sustainable Oil Palm Growers Cooperative (KPSM) in 2011. Its establishment is hoped to be able to solve problems faced by ISH such as lower offered FFB prices from fruit dealers, high cost of agricultural inputs, lower incomes, FFB yields and quality. In addition, via KPSM, smallholders are encouraged to manage their own requirements among members to elevate income focusing on oil palm business activities. There were obstacles at the initial stages as the establishment was the first of its kind introduced in Malaysia. A study by Nazirah *et al*. (2017) showed that nine factors which significantly influenced ISH in making decision as a member of the KPSM were gender, non-farm occupation, knowledge of members, community or society involvement, household income, commitment, community perception, oil palm management requirement and communication. The social contribution from such establishment was also determined (Sarmila *et al*., 2017) showing smallholders benefiting from networking, increased involvement in oil palm activities and job opportunities, and improved managerial skill among the members in the community.

Replanting programme using good planting materials has been proven to increase the competitiveness of Malaysian oil palm (Fauziah *et al*., 2017). The programme - Replanting and New Planting Assistance Scheme - has been initiated for ISH since 2011 under the 10^{th} Malaysian Plan. The scopes of assistance include land preparation, oil palm seedlings, fertiliser and other agricultural inputs (Zulkifli *et al*., 2017b). The scheme has created opportunity for farmers to fully maximise land use by implementing crops or livestock integration with oil palm. There are several types of crops recommended for integration with oil palm, however only a few, *i.e.* pineapple, papaya, banana and yams, that have potential to increase incomes are chosen by smallholders. More importantly, the selected crops must not affect the oil palm yields. Salak palm is another crop that has recently been identified for integration with oil palm (Norkaspi and Raja Zulkifli, 2017). Based on survey to recipients of crops and livestock integration programme, they prefer crop to livestock integration (Zaimah *et al*., 2017). Most of the recipients (92%) prefer planting banana to other crops mainly because it is non-seasonal and has a better demand. It is estimated that smallholders who continue their integration activities will have a potential monthly income exceeding RM 4000.

Biomass and Bioenergy

Palm biodiesel. Palm biodiesel has been used as an alternative fuel. Of the global biodiesel production of 35.19 million tonnes in 2017, 30.6% was palm biodiesel (Oil World, 2018). In Malaysia, 720 410 t of palm biodiesel were produced last year of which 235 291 t were exported mainly to the EU, 358 586 t used for local B7 blending and the remaining 126 533 t used as oleochemicals (MPOB, 2018; Unnithan, 2018). The production technologies of palm biodiesel continue to be researched. Recently, the traditionally used (homogeneous) catalyst for transesterification of PO, NaOH was replaced by calcium diglyceroxide, a heterogeneous catalyst, with Na_2CO_3 added as a precipitating agent for the unreacted Ca^{2+} ions. This approach yielded up to 94% conversion, producing good quality biodiesel (Pannilawithana and Pathirana, 2017). The conversion of PO and PKO into biodiesel via transesterification using free *Aspergillus niger* lipase was optimised via Response Surface Methodology (RSM) (Kareem *et al*., 2017). High biodiesel yields were achieved (>90% for PO and ~90% for PKO) at 40°C, 3:1 methanol-oil molar ratio and 5–7.5% enzyme. The resulting biodiesel fuel properties were comparable with the American (ASTM D6751) and European (EN 14214) standards; but, process efficiency and economic viability need to be further improved. Lipase in fermented solids derived from bagasse enriched with emulsified soyabean oil was used to catalyse solvent-free ethanolysis of PO (Galeano *et al*., 2017). A 90% maximum conversion was achieved using 4.5:1 ethanol-PO molar ratio with ethanol added to the shake flask in three steps during 48 hr. In contrast, a packed-bed reactor (5.5:1 ethanol-PO molar ratio, 4-step ethanol addition) yielded 89% conversion in 30 hr. The regenerated catalyst achieved 66% conversion after the 5th cycle successive 30 hr run in the reactor. The potential environmental impact of palm-based biodiesel production via life cycle assessments can vary greatly, depending on model choices (consequential and or attributional), co-product utilisation, technology improvements, and land use change (direct and indirect) (Prapaspongsa *et al*., 2017).

Malaysia is currently implementing a mandatory B7 national biodiesel programme (Jalil *et al*., 2017). To support uses of higher palm biodiesel-based blends in the transportation sector, testing on compression ignition engine using: (1) biodiesel (B100), (2) diesel-palm biodiesel blend (B20), and (3) diesel-PO blend (PO20) at zero to full loads was conducted (Gad *et al*., 2017). Blends of diesel with palm biodiesel up to 20% show reasonable performance and exhaust emissions compared to petroleum diesel. Blending palm biodiesel with pentanol (10%-20%), the latter acting as an oxygenated additive, reduced exhaust emissions of CO, HC, NOx and smoke (Radhakrishnan *et al*., 2017). A systematic review on palm biodiesel's current production issues, benefits and constraints for its implementation and specific use in diesel engines, along with its ability to meet stringent regulations and standards enforced in EU and USA was conducted (Mat Yasin *et al*., 2017).

Biodiesel production from PO via non-traditional approaches was explored too. A 5-wt.% bioadsorbent from oil palm empty fruit bunch (EFB) was able to remove 89.7% residual methanol, 81.7% water, 36.7% free fatty acid and 98.6% potassium from waste cooking oil biodiesel under continuous stirring at 500 rpm for 1 hr (Ahmad Farid *et al*., 2017). The purification method is cost-effective and the derived biodiesel meets the European Biodiesel Standard (EN14214). In addition, hydrogenated palm oil (HPO) was catalytically cracked via pyrolysis at 350°C-500°C to obtain a long-chain hydrocarbon-like diesel (Xu *et al*., 2017). The spectroscopic elucidation of the product revealed a pyrolysis pathway involving fatty acids deoxygenation and decarboxylation. The study showed that HPO is a better bioresource compared to other PO pyrolysis feedstocks.

A new marine strain, *Rhodococcu*s sp. YHY01 accumulates triacylglycerols and is able to produce fatty acids using oil palm biomass hydrolysate as carbon source (Bhatia *et al*., 2017). The process avoided various steps required to remove inhibitory compounds commonly employed in conventional bioconversion of lignocelluloses into biofuels, and enhanced biomass and fatty acid productivity compared to glucose. The biodiesel produced had more superior fuel properties compared to algal and petrodiesel. A microalgae species, *i.e. Chlorella vulgaris* UMACC 001 has shown to exhibit high oil to biomass ratio when cultured in 5% of an inexpensive and carbon-rich feedstock, palm oil mill effluent (POME) at different growth conditions (Idris *et al*., 2017). The harvested and characterised microalgal oil had similar characteristics to that of PO as a biodiesel feedstock. Ahmad *et al*. (2017) demonstrated that microbial oil from EFB hydrolysate is a possible feedstock for biodiesel production by the fungus, *Mucor plumbeus*. The spraying of pressurised water-steam (3450 kPa) at 150°C onto the surface of EFB resulted in ~94 wt.% recovery of residual CPO (Md Yunos *et al*., 2017). The fatty acid composition of the derived biodiesel was comparable to that derived from the fresh CPO. The remaining lignocellulosic materials possess high quality for deployment in the production of biofuels.

Biomass pre-treatment. Oil palm biomass (from oil palm plantations and PO milling) remains as an attractive substrate for renewable cellulose production (Noorshamsiana *et al*., 2017a). To convert the biomass, pre-treatment is required. Palma Medina *et al*. (2017) used DNA isolated from the soil to form a novel metagenomic library of cellulases to treat EFB. The cellulases showed possible exoglucanase and β-glucosidase activity at pH 4-10 and 30°C-60°C. Further, oil palm frond (OPF) was pre-treated with a mixed acid-base catalyst (HCl:NaOH) and enzymatically saccharified to produce >90% yield for glucose within 10 hr with ~85% digestibility for 72 hr (Jung *et al*., 2017). The alkaline H_2O_2 pre-hydrolysis followed by HCl hydrolysis of OPF yielded microcrystalline cellulose with an increased crystallinity (Owolabi *et al*., 2017).

Sulphite-based pre-treatment was employed to enhance enzymatic scarification by removing 38.8% lignin and dissolving 93.9% xylose from the treated oil palm trunk (OPT) (Noparat *et al*., 2017). Using an upgraded seawater solution with 5% (w/v) NaOH, the pre-treated EFB was more highly delignified and possessed higher reducing sugar yields than by pre-treatment using $NaCO_2$ and palm kernel ash (Ismail *et al*., 2017). Acetic acid was used to pre-treat palm kernel shell (PKS) to produce an improved reducing sugars yield of 40.4 mg g^{-1} biomass (Rattanaporn *et al*., 2017). A two-step peracetic acid-alkaline peroxide treatment of EFB fibre removed >98% of lignin at mild temperatures (20°C-35°C), resulting in nearly 210-fold glucose recovery compared with that of untreated biomass (Palamae *et al*., 2017).

Solid-state fermentation of EFB using a novel *Aspergillus niger* strain isolated from oil palm plantation produced xylanase as a potential hydrolytic enzyme to convert xylan to xylo-oligosacharides and pentose (Ajijolakewu *et al*., 2017). Through sequential dilute acid-microwave alkali pre-treatment, the treated EFB can serve as a potential cheap substrate for succinic acid production via simultaneous saccharification and fermentation using *Actinobacillus Succinogenes* (Akhtar and Idris, 2017). Total glucose yield (enzymatic saccharification yield x pre-treatment solid recovery yield) served as the single response variable instead of multiple response variables in all other studies to optimise pre-treatment of EFB through RSM (Tye *et al*., 2017).

Recently, ionic liquids (IL) have been explored in pre-treatment of oil palm biomass. For example, a methylimidazolium-based IL was combined with $InCl_3$ catalyst to depolymerise EFB and mesocarp fibre (MF) for subsequent ethyl levulinate conversion (Tiong *et al*., 2017). The IL-based catalytic system can be recycled three times. The IL- and alkali-pre-treatment led to fractionation of cellulose, hemicellulose and lignin from oil palm biomass. IL was recovered and reused for four cycles (Mohtar *et al*., 2017). Deep eutectic solvent has shown potential successive in swelling and dissolving OPT (Abdulmalek *et al*., 2017; Zulkefli *et al*., 2017c). In addition, divalent ($CuCl_2$) and trivalent ($FeCl_3$) inorganic salts assisted by H_2O_2 and sodium persulphate were effectively used for recovery of xylose from the stalks of OPF (Loow *et al*., 2017).

New technologies such as one-pot oxidative-hydrolysis employing $Cr(NO_3)_3$ metal salt (Chen *et al*., 2017) and 2,2,6,6-tetramethylpiperidine-1-oxy-mediated oxidation and sonication (Rohaizu and Wan Rosli, 2017) were effective for production and isolation of nanocelluloses from EFB. The nanocelluloses had higher crystallinity index, and exhibited high thermal stability in composite material synthesis. The physico-chemical properties of nanocellulose prepared via one-pot process were comparable to products isolated via conventional multistep purification approach (namely dewaxing, chlorite bleaching process, alkalisation and acid hydrolysis). The isolated nanocelluloses are being converted into biofuels and biomaterials.

Lignocellulosic biofuels. The potential of oil palm biomass as a bioenergy source was intensively researched. Ozturk *et al*. (2017) compared the biomass energy generation in Malaysia and Turkey in terms of policy, strategy, technology efficiency and population density. Although both countries are rich in biomass resources, they have different fundamental issues to tackle in future bioeconomy development. Separately, various oil palm biomass types in Malaysia were assessed for their important fuel and other physico-chemical properties, and their resource data in totality were provided as a reference for commercial bioresource exploitation (Loh, 2017). The huge potential biomass energy from oil palm and other residues in Sabah, Malaysia was estimated at ~267 179 818 GJ yr^{-1} (Suzuki *et al*., 2017), of which oil palm alone contributed to 263 635 079 GJ yr^{-1} (98.7%) or 2288 MW power at 25% power plant efficiency and 8000 hr yr^{-1} operation, *i.e.* about 3.8 times of total electricity supply in 2010 in Sabah. In Sarawak, Malaysia, the majority of oil palm growers agreed that utilisation of EFB and POME would bring greater sustainability impacts in oil palm plantations compared to PKS and MF but were uncertain on their commercial values (Phang and Lau, 2017).

A simulated model of a combined heat and power (CHP) plant in a palm oil mill fueled with biomass wastes was constructed to optimise energy generation to mimic conventional CHP plant (Wu *et al*., 2017). Three different fuel combinations: (1) EFB and PKS, (2) MF co-fired with biogas, and (3) PKS, EFB and biogas with preheaters, were evaluated. All three were able to produce enough electrical power and heat (steam) to meet the energy demand for PO processing, with potential extra energy for exporting to nearby areas. In order to harness most of the economic and environmental benefits from EFB, a retrofitted system that co-fired hydrothermally treated EFB (at 0%, 10%, 25%, and 50% mass) with coal was simulated through a computational fluid dynamics model (Darmawan *et al*., 2017). The study validates that 10%-25% mass fraction is the most preferred co-firing condition. The proposed integrated co-firing system shows very low energy consumption for feedstocks preparation with a net ~40% power generation efficiency. Besides, an energy-efficient integrated system incorporating EFB gasification, POME digestion and additional organic Rankine cycle was established in a palm oil mill to fully use both the solid and liquid wastes for power generation (Aziz *et al*., 2017). A total of 8.3 MW power was generated at a 30.4% power generation efficiency. The syngas produced can be used for biomass drying, biogas for generating both electricity and heat and the recovered unused heat for electricity generation. The sustainability of grid-connected oil palm biomass renewable energy industry in Malaysia was evaluated based on resource supply, energy system efficiency and electricity interconnectivity from the participating mills to the national grid (Umar *et al*., 2017). A workable framework incorporating biomass policy and industry roadmap is required to harmonise the upstream and downstream PO processing for a circular economy development.

Besides thermal-chemical conversion such as pyrolysis, more advanced biomass-to-bioenergy technology was employed. Oil palm fibre subjected to thermoliquefaction using supercritical ethanol in a semi-continuous process produced 56% to 84% of bio-oil yields dependent on temperature used (Oliveira *et al*., 2017). At lower temperature (300°C), sugar derivatives are the major bio-oil component, while alcohols and phenolic are the major compounds present at higher temperatures. In addition, PKS underwent thermochemical liquefaction using sub- and supercritical water to produce 6.5-15.6 wt % bio-oil at 330°C-390°C (Chan *et al*., 2017b). As expected, phenolic compounds were the major component of bio-oils for all reaction conditions investigated. One interesting finding was that the lignin (rather than cellulose) in the oil palm biomass was fractured and hydrolysed/liquefied into aromatic compounds when longer residence time was applied. These results imply that biomass having high lignin content may yield more bio-oil than reported in the literature. The other thermochemical liquefaction approach using EFB is catalysis by Fe_3O_4 or H_2 in the presence of sub- and supercritical tetralin yielding 91.8%, and 97.1% conversion at 400°C, respectively (Koriakin *et al*., 2017). The n-Dodecane as solvent produced >77% conversion but at >10 MPa pressure using the same catalytic approach. Tetralin is better in liquefying EFB into aromatic derivatives whereas some aliphatic components form in the other system. Under supercritical hydrothermal liquefaction assisted by 1.0 wt.% metal oxide catalysts (CaO, MnO, CeO_2 and La_2O_3), EFB produced ~1.4 times higher maximum relative bio-oil yield than that without catalyst at 390°C, 25 MPa, and 1 hr (Yim *et al*., 2017).

A group of researchers optimised the production of PKS-char, EFB-char and palm oil sludge-biochar via pyrolysis in a stainless steel bed reactor placed in a horizontal tubular furnace (Lee *et al*., 2017a,b). The biochars are suitable for biofuels and for heavy metal removal. Kabir *et al*. (2017) pyrolysed MF and OPF in a slow-heating fixed-bed reactor, producing bio-oils that are suitable as fuels and chemicals. They also provided an insight into how the various biomass characteristics could affect pyrolysis for producing high-grade biofuel and biochemical precursors (Kabir and Hameed, 2017). EFB-biochar and rice husk biochar were produced by Yavari *et al.* (2017). The former possessed better sorption capacities/efficiency in removal of polar herbicides due to the presence of higher amount of oxygen-containing functional groups. The evolution of the basic physico-chemical characteristics (chemical composition, functional groups, pore structure and crystallographic structure) of PKS biochar from 250°C to 750°C was systematically investigated, providing useful information for high value-addition of the char (Ma *et al*., 2017).

In order to optimise EFB utilisation, a mathematical model for EFB multi-production supply chain was established to serve as a supportive tool to provide economic potential for investments (Abdulrazik *et al*., 2017). A mixed spent bleaching earth (SBE) and EFB (30:70 wt/wt) yielded biomass briquettes with acceptable quality as a solid biofuel (Srisang *et al*., 2017). Biomass pellets from oil palm leaves and OPF, para-rubber leaves litter and branches and their blends were exploited, too (Wattana *et al*., 2017). The hydrothermally treated, water-washed and pelletised EFB possessed higher ignition temperatures with a more uniform combustion profile as a solid fuel (Zaini *et al*., 2017). A life cycle impact assessment study indicated that the main environmental impacts of EFB pellet production are fossil depletion, climate change and particulate matters emission due to heavy dependence on grid-connected electricity; hence, upgrading the pellet quality and reducing the associated environmental impacts are required to make the production competitive (Nasrin *et al.*, 2017a).

Torrefaction was also studied for oil palm biomass thermal degradation as solid biofuels. Sukiran *et al*. (2017) evaluated various torrefaction technologies for their effect on fuel characteristics of oil palm solid wastes. Torrefaction of EFB in a fixed-bed tubular reactor via an O_2- and CO_2-enriched wood pellet combustion gas and higher temperature showed lower solid yield than that in N_2 gas, and higher calorific value (Uemura *et al*., 2017). A kinetic model for EFB torrefaction at 240°C-270°C was established to predict the anhydrous biomass weight loss during thermal degradation (Mohd Harun *et al*., 2017). The same group also established a model correlation to predict the higher heating value (HHV) of torrefied oil palm biomass based on proximate analysis (Abdul Wahid *et al*., 2017).

Although thermal processing of oil palm biomass via microwave technology has been thoroughly studied, the fundamental understanding of dielectric properties of biomass, which is crucial for designing cost-effective biomass treatment systems, is still lacking. Salema *et al*. (2017) provided useful data on these properties for oil palm, rice, coconut and sawdust. The dielectric constant and loss factor decrease during drying and pyrolysis stages, but increase drastically during char formation stage, probably due to high conductivity of the char material. In addition, the variables for microwave pyrolysis of OPF, *i.e.* temperature, microwave power and N_2 flow rate, were studied, showing correlation between H_2 yield and N_2 flow rate while biochar yield is susceptible to temperature change (Hossain *et al*., 2017). The optimised conditions for maximum H_2 and biochar production are: 450°C, 400 W microwave power and 955.25 cm^3 min^{-1} N_2 flow rate. Particularly, the microwave pyrolysis of PKS yielded a zero-sulphur biochar with 23-26 MJ kg^{-1} HHV which is equivalent to conventional coal as a promising solid biofuel, pollutant adsorbent as well as soil conditioner (Liew *et al*., 2018). Interestingly, Omoriyekomwan *et al*. (2017) found formation of hollow carbon nanofibres (HCNF) arranged in high ordered carbon layers with two main tubular and bamboo-shape structures, occurred only during microwave pyrolysis of PKS (500°C and 600°C) and not via other methods. The mineral matters (metallic species) in the biomass and the temperature difference between the surrounding particles and particle core caused by microwave-induced heating are believed to have facilitated their growth via 'self-extrusion' of volatiles through nano-sized channels. The PKS-biochar coated with HCNF can potentially remove heavy metals from wastewater. Also, PKS produced via a microwave-assisted pre-carbonisation system at 300°C shows high HHV and low gaseous emission as a co-combustion solid biofuel (Zainal *et al*., 2017).

Biogas from POME. POME has frequently been the focus for bioenergy exploitation and environmental concerns. Due to its high organic content, POME can be detrimental if untreated and released to the environment; in contrast, the released biogas through anaerobic digestion (AD) of POME is a potential energy source for CHP generation. Malaysia demonstrated its expertise in biogas endeavours (capture and utilisation) through a nationwide implementation under the Economic Transformation Programme by highlighting important technological, financial and institutional elements (Loh *et al*., 2017a). Co-firing biogas in palm oil mill biomass boiler has shown great potential in reduction of boiler stack opacity (~20%) and dust and particulate concentrations (>50%) (Nasrin *et al*., 2016). Cost-effective biogas capture and its application requires a properly configured system integrating all of the technical aspects concerning pH, temperature, organic loading rate (OLR), hydraulic retention time (HRT), mixing rate, pressure, equilibrium, nutrient and microbial activities. A system that features high biogas/methane composition at lower HRT and OLR is feasible (Ohimain and Izah, 2017).

Biogas productivity can be enhanced via many different approaches. One example is integrated ultrasonic-membrane technology (Abdurahman *et al*., 2017) showing >98% overall chemical and biological degradation of POME with its biogas containing up to 81% methane. A two-step thermophilic fermentation of POME under non-sterile conditions by xylanase was able to enhance biogas production by three-fold (Prasertsan *et al*., 2017). POME inoculated with dairy manure at pH 6.8 and 37°C in a continuously stirred tank reactor at 10 days HRT led to a more than two-fold increase of biogas yield and methane content; and ~45% chemical oxygen demand (COD) reduction compared to that produced in the absence of inoculum (Krishnan *et al*., 2017). To further enhance methane production, POME and EFB were co-digested separately with sewage sludge (chemical and biological) under liquid and solid AD conditions, respectively (Suksong *et al*., 2017a). While the former exhibited a positive synergistic increase of methane yield (1.2%-5.7%), the latter showed a lower yield compared to single-digestion. Microbial inhibition occurred with an increased substrate concentration (total solids between 6%-42%) in both AD systems. In fact, although co-digesting POME (2 g-10 g volatile solids) using EFB size of 3.3 cm - 6 cm showed acceptable biodegradability and methane production, the resulting yield was 37% lesser than that using POME alone (Saelor *et al*., 2017). The same group of researchers further showed the great potential of EFB, OPF and OPT in thermophilic solid-state AD (Suksong *et al*., 2017b). Factors such as feedstock-to-inoculum ratio (2:1, wt/v), carbon-to-nitrogen mass ratio (C:N = 40:1) and total solids (16%) greatly optimised methane yields.

POME undergoing AD in the presence of natural microorganisms produced a mixture of H_2 and methane (biohythane) that can either be used as a chemical, or a carrier for gas-to-energy combustion (Mamimin *et al*., 2017). The presence of volatile fatty acid in POME, particularly butyric and propionic acids, causes low methane conversion efficiency under thermophilic conditions. The VFA mixtures at different concentrations provide interactive effects in influencing and inhibiting the bacteria and archaea communities during methanogenesis. Thus, their presence in high concentrations (>8 g litre^{-1}) should be prevented in two-stage AD for biohythane production. In addition, production of H_2 from pre-settled POME was improved in a modified upflow anaerobic sludge blanket fixed film reactor, achieving 0.31 litre H_2 g^{-1} COD conversion at 0.5 m hr^{-1} velocity and 1.7 litres per day POME flow rate (Mohammadi *et al*., 2017). The POME that underwent dilute acid pre-treatment was able to enhance biohydrogen production via thermophilic dark fermentation by mixed culture (Mahmod *et al*., 2017).

In addition to POME, other types of oil palm biomass are good feedstock for biohydrogen production. Several MgO supported Ni, Cu and Zn oxides were synthesised for catalytic gasification of OPF in supercritical water to produce H_2 (Mastuli *et al*., 2017). This study showed that catalysts with larger specific surfaces did not necessarily bring about the highest catalytic performance due to differentiated H_2 selectivity influenced by particle dispersion, basicity and bond strength. A two-stage lime- and enzyme-pre-treated thermophilic process of OPT hydrolysate produced biohydrogen and methane (Sitthikitpanya *et al*., 2017). The employed process was able to produce 2.7-fold higher sugar yield than that of untreated OPT, with a total 83% COD removed.

More researches have geared towards enhancing biohydrogen from POME. For example, photofermentation assisted by ultrasonication of a combined POME: pulp and paper wastewater (25:75, v/v) by *Rhodobacter sphaeroides* improved biohydrogen production (Budiman *et al*., 2017). Ultrasonication at a middle range of amplitude and duration was able to improve light distribution, hence increasing biohydrogen yield by 45%, with a total 52% COD removal compared to the negative control. An effective activated carbon-based carrier/biofilm consisting of 0.44 cm^3 g^{-1} pore volume was best for adhering and colonising the thermophilic H_2 producer - *Thermoanaerobacterium thermosaccharolyticum* (Jamali *et al*., 2017). This biofilm was able to hydrolyse cellulosic fibre into simple sugar in all diluted POME substrates. A newly isolated mesophilic *Bacillus anthracis* strain from POME sludge tested on synthetic substrate (yeast and mannose) was able to produce a maximum of 2.42 mol H_2 mol^{-1} mannose at 35°C and initial pH 6.5 (Mishra *et al*., 2017). Using the results, the calculated specific H_2 production potential from POME is 236 ml H_2 g^{-1} COD. Further, 0.66 mol H_2 mol^{-1} total monomeric sugars is attainable at 37°C for 24 hr – a 3.5-fold increase by an engineered *Escherichia coli* compared to wild type *E. coli* (Taifor *et al*., 2017).

Lately, POME research has intensified on integrating biogas within a palm oil mill complex and advancing biogas into bio-compressed natural gas (BioCNG) and biohydrogen. The world's first commercial 400 m^3 hr^{-1} BioCNG plant from POME has been established at Sungai Tengi Palm Oil Mill, producing a >94% enriched methane content in biogas with a high calorific value (35.95 MJ Nm^{-3}), similar to natural gas specifications (Nasrin *et al*., 2017b). A Fuzzy-model optimisation approach was developed to maximise the utilisation pathway and distribution network of the PO milling co-products (from oil palm biomass, POME up to bioCNG) through clustering of palm oil mills for multiple-production (Theo *et al*., 2017). The simulated factors – feed-in-tariff, quota variation and transhipment pathway of bioCNG showed that the proposed PO processing cluster can increase mill's annual income. In a separate study, an optimal BioCNG injection into natural gas grid and distribution to potential identified areas in the Peninsular Malaysia was assessed using the BeWhere techno-economic model considering cost and emission minimisation throughout the biogas supply chain (Hoo *et al*., 2017). In order to make bioCNG a competitive energy option, biogas injection stations must be within vicinity to biogas capturing plants.

Biomaterials. Oil palm biomass can be made into many different bioproducts besides bioenergy applications. Magnetic biosorbents made from sonication of a mixed EFB, EFB celluloses and kapok fibre can be used to remove heavy metal ions in wastewater treatment (Daneshfozoun *et al*., 2017). Chitosan composite film reinforced with cellulose from EFB performed well for cadmium ion removal (Rahmi *et al*., 2017). Lignins serve as a suitable green material for phenolic resins production (Faris *et al*., 2017). Lignins fractionated from EFB via Kraft process had better structural and thermal characteristics than those by organosolv pulping. Lignin produced through similar treatment on OPF and incorporated with m-cresol showed better antioxidant activity (Sa'don *et al*., 2017). PKS powder-based biosorbent has the ability to remove Cu and the Cu-coated material is a potential heterogeneous catalyst (Kushwaha *et al*., 2017). Activated carbon derived from EFB fibre is effective for urea adsorption in wastewater treatment (Ooi *et al*., 2017). The fibre can be an alternative natural acoustic material for noise control (Or *et al*., 2017). Other bioproducts developed are: (1) acetoin from MF hydrolysate via engineered *E. coli* (Mohd Yusoff *et al*., 2017), (2) 3,4,5-trihydroxycinnamic acid (a strong antioxidant) synthesised from POME-extracted p-coumaric acid and caffeic acid (Pinthong *et al*., 2017), and (3) bioflocculant from POME (Nurul Adela *et al*., 2017).

Oil palm ash, a milling by-product, can be converted into a mesoporous lithium-doped (10 wt %) zeolite which can catalyse transesterification of glycerol and dimethyl carbonate for glycerol carbonate (GC yield, 98.1%) under optimised reaction condition (Khanday *et al*., 2017). The developed catalyst was capable of maintaining its catalytic activity after five subsequent reuses. As a highly pozzolanic material, oil palm ash and palm oil clinker have been evaluated as a cementitious material for concrete replacement (Thomas *et al*., 2017; Karim *et al*., 2017). A zeolite-based adsorbent was synthesised via two-step alkaline fusion and hydrothermal treatment of oil palm fly ash (Kongnoo *et al*., 2017). The acid-activated zeolite shows enhancement in its CO_2 adsorption capacity.

The refining by-product, SBE, either in activated or neutral form, is a bentonite-based earth/clay that possesses many positive attributes due to the available active charge sites and surface functional groups in favourable orientation for surface binding activities (Loh *et al*., 2017b). These excellent physico-chemical properties make SBE a bioactive material for water/wastewater treatment and as biofertiliser vital for soil amendment in agricultural applications (Loh *et al*., 2013). Last but not least, residual oil in palm pressed fibre after milling process was recovered using aqueous enzymatic extraction, yielding phytonutrient-rich PO (Noorshamsiana *et al*., 2017b).

Regulatory requirement of POME final discharge. In 2006, the Department of Environment (DOE), Malaysia had imposed a more stringent law - a stricter biological oxygen demand (BOD) of 20 ppm - pertaining to the discharge of POME in Sarawak and some environmentally-sensitive areas in Sabah. In 2015, the Sarawak state government revised the specification to 50 ppm for a three-year grace period (personal communication). Many tertiary treatment technologies have been researched, but the majority are unable to meet the BOD 20 ppm final discharge consistently (Liew *et al*., 2015; Zainal *et al*., 2017). Conventional POME treatment with ponding and piping systems is likely associated with meeting but not exceeding the final discharge BOD limit set. A renewed interest in understanding more deeply about POME scale deposits at various stages of treatment has shed light, as these materials famously known as struvites can be an alternative source of phosphorous mineral for fertiliser application (Muzzammil *et al*., 2017).

In conventional POME tertiary treatment, many new innovations were developed. Recent POME polishing technologies were reviewed (Bello and Abdul Raman, 2017). Of these, the authors foresee the future prospect of advanced oxidation processes such as Fenton and photocatalysis for large scale treatment, provided that cost-effectiveness is achieved when integrating with the existing POME treatment technologies. The photocatalysis of diluted POME with TiO_2 and O_2 supply showed >50% overall degradation (Ng and Cheng, 2017). One important factor in POME treatment – biosorption of granular sludge – via a sequencing batch reactor was modelled by investigating the oxidisable organic matter liquid-solid mass transfer and kinetics (Fulazzaky *et al*., 2017). Mass transfer of granular sludge and role of internal packing of a hybrid anaerobic bioreactor through dark fermentation of POME was also studied (Zinatizadeh *et al*., 2017). A microbial granule consisting of photosynthetic pigments was grown using POME, showing good biomass concentration, stability and sedimentation (Najib *et al*., 2017).

A microbial fuel cell (MFC) was combined with anaerobic membrane bioreactor for POME treatment (Tan *et al*., 2017b). The combined system exhibited better fouling control, overall COD removal efficiencies and filtration performance compared to the absence of MFC. The other new system 'spiral–screw dielectric barrier discharge plasma' reduced ~82% COD of POME, but did not meet the required POME discharge limit (Nur *et al*., 2017). An immobilised oleaginous microalgae was used in phytoremediation of secondary POME in a fluidised bed photobioreactor (Cheirsilp *et al*., 2017). This approach eases harvesting and improves the biomass and lipid productivity of *Nannochloropsis* sp. for both renewable energy production and tertiary treatment. Duckweed (*Lemna minor*) and microalgae (*Chlamydomonas incerta*) were able to treat POME partially and subsequently be used as organic fertiliser (Kamyab *et al*., 2017). A synthesised copper nanoparticles from *Commelina nudiflora* extract displayed potential as a biocontrol agent for POME treatment (Kuppusamy *et al*., 2017).

Interestingly, recent research shows that SBE prepared by combined acid and heat regeneration has promising potential in decolourising and reducing the BOD of POME final discharge at ~70% and ~50% removal rate, respectively though the practicality of this approach on an industrial scale is uncertain (Abd Majid and Che Mat, 2017). In a separate study, pyrolysed activated carbon from

EFB achieved a ≥90% decrease of BOD, COD and colour adsorption from the final discharge of POME (Abd Wafti *et al*., 2017). In addition, treatment of POME by steam-activated carbonised MF met river water quality discharge limits (Ibrahim *et al*., 2017).

Palm Oil in Food and Nutrition

With the world population growth projected to gradually reach 11.2 billion by the year 2100, the ever-increasing need to ensure a continuous supply of healthy and nutritious food to meet this population demand serves as a grand challenge (United Nations, 2017). In 2017, PO maintained its position as the most produced and consumed vegetable oil in the world (Oil World, 2017) despite concerns raised for nutritional, toxicological and environmental aspects of PO. PO's high saturated fat content relative to other edible oils has been negatively perceived. Recent concern has also been raised about the presence of process contaminants 3-monochloropropane-1,2-diol (3-MCPD) and glycidol esters (GE) in refined PO due to their potential toxicity (Clemens *et al*., 2017). However, a plethora of scientific research suggests that PO consumption has no harmful effects on human health, in particular on the risks in the development of cardiovascular diseases and cancer. PO thus remains the popular choice for the food industry worldwide due to its extremely competitive price, excellent oxidative stability and long shelf-life in addition to its proven versatility as an important ingredient in a vast range of food products (Habi Mat Dian *et al*., 2017).

In charting the way forward, research on PO in food and nutrition continually focuses on improving the quality and food safety aspects of the oil through adoption of new and transformative technologies, highlighting the nutritional benefits of its abundant phytonutrients (Kushairi *et al*., 2017). PO is well-known to contain the highest levels of naturally-occurring vitamin E tocotrienols and pro-vitamin A carotenoids among edible vegetable oils (Ng and Choo, 2012; Loganathan *et al*., 2017). In addition, there is growing evidence on the health promotion effects of other phytonutrients present in PO such as phytosterols, squalene and coenzyme Q10. Clinical studies have reported on the beneficial effects of palm tocotrienols on neuroprotection and cognitive function, cancer, cardiovascular health, immune modulation, antioxidant and skin protection in humans (Meganathan and Fu, 2016). Carotenoids in red palm oil have been associated with numerous health benefits through their potential effectiveness in combating vitamin A deficiency, heart diseases, antiatherogenesis, severe haemorrhaging, hypertension, cancer protection, infections, reproductive deficiencies in both males and females, diabetes, chemotherapy side-effects and hypobaric conditions (Dong *et al*., 2017; Loganathan *et al*., 2017).

Recent investigations on the potential anti-cancer properties of tocotrienols in PO have shown that tumour-targeted niosomes entrapped with tocotrienols significantly improved the therapeutic efficacy of tocotrienols in human breast cancer (Tan *et al*., 2017c). The anti-proliferative activity of γ-tocotrienols in breast cancer cells was significantly enhanced via entrapment in niosomes. Significant tumour-supression by tocotrienols encapsulated in niosomes was observed in a murine xenograft model, suggesting tumour-targeted encapsulated tocotrienols as a promising delivery system in cancer therapy. Abu-Fayyad and Nazzal (2017) confirmed previous findings in the literature that γ- and δ-tocotrienols entrapped in nanoemulsions possessed greater anti-tumour activity in breast and pancreatic cancer cells than α-tocopherol and α-tocotrienol isomers.

Recently, acute supplementation of a single-dose γ- and δ-tocotrienols with a high-fat challenge showed no effect on the concentration of insulinemic, low-grade anti-inflammatory and anti-thrombogenic markers responses in metabolic syndrome subjects (Che e*t al*., 2017). In a separate study, acute supplementation of palm-tocotrienols and tocopherol mixtures on metabolic syndrome subjects have indicated the lack of inhibitory effect on platelet aggregation, platelet activation, coagulation and inflammatory status (Gan *et al*., 2017). Both of these studies displayed the bioavailability of tocotrienols in plasma; however, longer-term studies are needed to translate the impact of tocotrienols to metabolic outcome in humans.

By mid-2018, the USA Food and Drug Administration (FDA) will require total removal of partially hydrogenated oils from human food (USFDA, 2015) to remove *trans* fats, due to their proven damaging effect on cardiovascular disease (CVD) and coronary heart disease. PO has emerged as one of the most suitable natural partially hydrogenated oil substitutes due to its balanced ratio of saturated to unsaturated fatty acids and abundance of phytonutrients, contributing to the excellent oxidative stability of the oil. PO contains approximately 50% of the saturated palmitic and stearic acids, located predominantly at the sn-1 and sn-3 position of the glycerol backbone. The unique triacylglycerol structure of PO has resulted in less profound effects on the elevation of low-density lipoprotein cholesterol compared to animal and dairy fats. Moreover, PO exhibits similar health-promoting effects as olive oil: comparable effects on total cholesterol, low-density lipoprotein (LDL) and high-density lipoprotein (HDL) cholesterols and triglyceride levels in human studies (Voon *et al*., 2011).

In spite of the numerous studies demonstrating the healthful benefits of PO, the oil palm industry continues to encounter negative perceptions due to the potential health risks associated with 3-MCPD, its esters and GE. This issue was heightened by the release of the European Food Safety Authority (EFSA) Report in 2016 which issued a potential health warning on chloropropanols, specifically identifying 3-MCPD as a possible human carcinogen classified by the International Agency for Research on Cancer (IARC) (EFSA, 2016). Although no toxicological studies on human subjects have proven any adverse health effects of these compounds a provisional maximum tolerable daily intake (TDI) of 2 μg kg^{-1} body weight was recommended by several regulatory and authority bodies based solely on previous *in vitro* and *in vivo* studies demonstrating toxicity of the compounds on renal and testicular organs of rats, which were then projected upon humans. In fact, 3-MCPD, its esters and GE are present in all refined vegetable oils at differing levels. It is important to note on the lack of human studies to assess and confirm possible effects of long-term 3-MCPD exposure at different levels over a substantial period of time. A recent *in vivo* study by Aasa *et al*. (2017) confirmed earlier studies that 3-MCPD exhibited no genotoxicity in mice through the monitoring of micronuclei frequency in erythrocytes, despite relatively high doses of 3-MCPD exposure. Lee *et al*. (2017c) concluded that 3-MCPD did not show carcinogenic potential in mice administered with 3-MCPD daily for 26 weeks. The genotoxicity of glycidol was generally reported to be more of a concern and further human studies are warranted to evaluate the effects of glycidol on human health.

Meanwhile, concerted efforts have been undertaken by oil palm industry stakeholders in the last decade to minimise and reduce the formation of 3-MCPD esters and GE throughout the entire oil palm life cycle from the plantation to refined product. Mitigation approaches were proposed through the choice of fertilisers, implementation of timely harvesting and fruit milling as well as employing milder processing conditions and utilisation of additional processing technologies such as short path distillation for their efficient removal (Clemens *et al*., 2017). Intensive R&D of robust analytical methods for the determination of 3-MCPD esters and GE in recent years has led to novel, fast and reliable techniques for the identification and quantification of these compounds in different food matrices using state-of-the-art high resolution instrumentation such as gas chromatography-mass spectrometry, gas chromatography-triple quadrupole mass spectrometry and liquid chromatography-high resolution mass spectrometry (Cheng *et al*., 2017; Genualdi *et al*., 2017; Jedrkiewicz *et al*., 2017). The urgency in addressing concerns pertaining to 3-MCPD esters and GE has resulted in a concentrated holistic approach within the palm oil industry in the past year to develop mitigation strategies throughout the supply chain, in addition to the food safety analysis of these compounds.

As 3-MCPD and GE are heat-induced process contaminants, investigations on the effects of different high temperature food preparation techniques such as deep fat frying have been initiated recently to mitigate 3-MCPD ester and GE levels during various cooking processes. Aniolowska and Kita (2016) reported that the GE content of PO decreased with increasing temperature and time during intermittent frying of potato chips, and this correlated with the degree of oil degradation. However, Wong *et al*. (2017a) reported that frying duration and temperature as well as salt concentrations had profound effects on the formation of 3-MCPD esters and GE during the deep-frying of potato chips in palm olein with the former decreasing at longer frying times and increasing at higher frying temperatures and salt concentrations while the latter increased with increasing frying time, temperature and salt concentration. The same authors reported similar increases in 3-MCPD esters with increasing concentration of salt while no effect on GE formation was observed during deep-frying of chicken breast meat (Wong *et al*., 2017b). By implementing shorter frying time and lower temperature, as well as the reduction or elimination of chloride during food preparation, the presence of 3-MCPD esters within finished food products may be minimised to levels well below the current regulatory limit, if not removed entirely.

PO utilisation in the food industry in the past year has seen continued growth through innovative and tailor-made products laden with functional nutrients through various food modification processes. For example, palm-based designer fats and nutraceutical supplements are being developed for various food applications and functionalities. Preservation of the valuable phytonutrients contained within PO, in particular the beta carotenes and vitamin E tocotrienols, and their application in isolated form in food products have facilitated their efficient delivery and release, and enhanced bioavailability while minimising degradation within the gastrointestinal tract of the human body through various encapsulation techniques. Delivery vehicles for microencapsulation of PO nutraceuticals include complex coacervates, lipid-based colloidal systems (*e.g*., solid lipid microparticles), chitosan-alginate microcapsules and with supercritical carbon dioxide solution-enhanced dispersions, among others (Brito-Oliveira *et al*., 2017; Rutz *et al*., 2017; Soukoulis and Bohn, 2017; Tan *et al*., 2017d).

An interspecific hybrid species of oil palm (*Elaeis oleifera* x *Elaeis guineensis*) yielded an oil dubbed the 'tropical equivalent of olive oil' containing a high percentage of oleic acid, carotenes and tocochromanols. Studies have shown that this new oil has favourable effects on cardiovascular health, and its antioxidant capacity in human plasma lipids and erythrocyte membrane lipids are similar to that of extra virgin olive oil, thus creating opportunities for increasing the oil's application in a myriad of food products in the near future including functional foods (Lucci *et al*., 2016; Pacetti *et al*., 2016; Ojeda *et al*., 2017). With the current awareness of the rise of CVD, metabolic syndrome and obesity worldwide, the global food trend has seen a remarkable shift in consumer preferences, not merely for more nourishing and wholesome natural food, but also food containing essential dietary nutrients and antioxidants. Hitherto, it is no wonder that the intrinsic nutrient-rich PO will continue to be a preferred oil and source of functional ingredients in households and food industry worldwide.

Palm-based Oleochemicals

The palm-based oleochemical manufacturing industry has contributed significantly to the economic growth of Malaysia. Two important palm products, *i.e.* PO and PKO, are converted into five basic oleochemical intermediates: fatty acid, methyl ester, fatty alcohol, fatty amine and glycerol. Hydrolysis of PO cleaves the triglyceride molecules into the corresponding fatty acids and glycerol, which then forms the basis of palm-based oleochemicals. Recent R&D efforts have focused upon oleochemicals derivatives such as bio-polyol for polyurethanes (PU), surfactants and bio-surfactants, bio-lubricants, agrochemicals and glycerol derivatives, and assessing the feasibility of processes/technologies, and their environmental impacts. However, oleochemicals compete stiffly with petrochemicals in various markets. With growing demand for eco-friendly chemicals and current price volatility of petrochemicals, palm-based oleochemicals are gaining better consumer acceptance.

Several palm-based polyols (Pioneer® from palm olein, Premier® from palm kernel olein, PolyME® from fatty acid methyl ester and PolyMO® from oleic acid) have been developed for their applications in PU foams and non-foam products (Hazimah *et al*., 2011). The oligomeric polyols synthesised from epoxidised methyl oleate and palm olein produce PU with good elastomeric properties (Hoong *et al*., 2017a). Many products are produced using PU such as automotive parts (pad dash panels and carpet underlays), sealants and adhesives, decorative panels, ceiling panel, insulation panel, flexible PU slabstock foam and coated fertilisers. Palm-based memory foam, characterised by its slow recovery after compression, was successfully formulated and utilised in pillows, upholstered furniture, flooring underlays, cushioning (*e.g.* neck cushions), and as foams for noise and vibration harshness control (Nurul' Ain *et al*., 2016). Recently, soft PU elastomers with >70% bio-based content was successfully prepared from PolyME® polyol and Pioneer® polyols, which serve as a platform for the development of transparent elastomers that can be used as soft energy-absorbing materials with potential use in pressure sensitive adhesives (Mohd Norhisham *et al*., 2017).

The cosmetics industry is now a huge luxury global market (MPOB, 2010). More recently, consumers have demanded natural resources to be used in cosmetics and personal care (CPC) products. CPC products cover four main categories: skin care, hair care, oral care and colour cosmetic in varying forms, *e.g.* lotion, cream, liquid, gel and stick. They can be formulated using palm-based oleochemicals such as glycerine, fatty acids (lauric, myristic, palmitic and stearic acids), fatty alcohols and their esters, which are natural, mild and globally acceptable, at levels ranging from 60% to 70% (Rosnah *et al*., 2011). One example is 9,10-dihydroxystearic acid (DHSA), a patented synthesis from palm oleic acid that is highly biodegradable (Razmah *et al*., 2015). DHSA is now used as a coating material to help increase colour intensity and improve glossiness in colour cosmetic products; and improve transparency, foaming and cleaning power of transparent soaps (Rosnah *et al*., 2015). In addition, polyhydroxyl estolides synthesised via a one-pot low temperature self-oligomerisation of oleic acid (Hoong *et al*., 2017b) acts as an emulsifier for CPC products.

Glycerol (glycerine), an important co-product from the biodiesel industry with three hydroxyl groups, is an ideal starting material for many chemicals via oxidation, polymerisation, reduction, and dehydration. Many new uses of glycerol have been identified through conversion into polyglycerols (polymeric materials), esters (emulsifier), glycerol alkyl ether (in cosmetic and liquid cleaner formulas), and other derivatives such as glycerol carbonate, glycerol metal complex, *etc*. Glycerol carbonate is one of the most potentially useful glycerol derivatives. The oligomerisation of glycerol carbonate produces polyhydroxylated oligomers rich in linear carbonate groups (Mw < 1000 Da). oligo-(Glycerol carbonate-glycerol ether) is a viable alternative to petroleum-based polyethylene oxide in the preparation of non-ionic surfactants (Holmiere *et al*., 2017). Crude glycerol can also be potentially fermented by a commercial strain, *Klebsiella pneumoniae* or a newly isolated *Kluyvera cryocrescens* from POME, to produce 1,3-propanediol which serves as a specialty platform chemical (Rosland Abel and Loh, 2017a, b).

One major end-use of oleochemicals is for preparing surfactants. The main surfactant type is anionic which acts as the key ingredient in making detergent and household cleaning products, from 10% to 30% of the total formulation (Razmah *et* *al*., 2006). The most common anionic surfactants are linear alkyl benzene sulphonates (LAS), fatty alcohol sulphates and fatty alcohol ether sulphates. The former is petrochemical-based while the latter two can be bio-based or derived from fossil fuels. LAS has been the major anionic surfactant used in detergent and household cleaning products for >30 years; but, the recent increase of crude oil prices coupled with successful commercialisation of oleochemical-based methyl ester sulphonates (MES) may change this situation. MES has been produced through direct suphonation of palm-based methyl esters since 2000 via a fully automated pilot plant at 20 kg hr^{-1} capacity (Razmah *et al*., 2006). The product shows superior properties over LAS in terms of detergency, biodegradation and also tolerance to different water hardness (Salmiah *et al*., 1998). The performance of MES-based powder and liquid detergents produced has been found comparable to leading LAS-based detergent brands currently available in the markets (Zulina *et al*., 2006). Furthermore, MES-based detergents are readily biodegradable in aquatic environment (Siti Afida *et al*., 2016; 2017). Liquid detergent formulated with MES successfully made its way to the shelf of Malaysian supermarkets, while powder detergent will soon follow suit with formulation already been taken up by another company (Zulina *et al*., 2017a).

PO and its esters exhibit good adhesion to metal, good lubricity, high oxidative stability and desirable viscosity index properties, and therefore serve as a suitable base fluid for various lubricant formulations such as grease, hydraulic fluid, insulating fluid for transformers, metal-working fluid and drilling fluid (Noor Armylisa's *et al*., 2016; Tang *et al*., 2017). Also, food-grade lubricants have been developed for food processing and PO milling equipment using palm-based esters emphasising on safety to prevent from any accidental contamination of biolubricant in food products (Yeong *et al*., 2010; Loh *et al*., 2016). Recently, a technology to produce palm polyol ester for biodegradable and non-toxic lubricants with low acidity has been developed which fulfils the industrial standard quality requirement (Zulina *et al*., 2017b). Synthesis of trimethylolpropane triesters and palm oil methyl esters was performed using a mixture of 1 wt% Ca and Sr oxides and 5 wt% SrO on CaO, yielding 88% of palm-based lubricant (Ivan-Tan *et al*., 2017).

Agrochemical (insecticide and herbicide) formulations, *e.g.* aqueous concentrates, emulsifiable concentrates, wettable powders, suspension concentrates, emulsion-in-water concentrates (EW), water dispersible granules, *etc.* are derived from active and inert ingredients. Inert ingredients from palm-based oleochemicals such as fatty acids, fatty alcohol ethoxylates, fatty alcohol ether sulphates, fatty amine oxide and glycerol esters are employed to increase the uptake and efficacy of active ingredients (*e.g.* deltamethrin as pesticide), improve wetting properties and/or spraying characteristics. Palm-based methyl esters are suitable green solvents for EW-based pesticide formulations (Ismail *et al*., 2014; Sumaiyah *et al*., 2017), to replace conventional petroleum-based solvents.

AREAS FOR IMPROVEMENT

Oil palm has been commercially cultivated in Malaysia since 1917, and the 100^{th} anniversary of this event in 2017 was widely commemorated throughout Malaysia. As nature's gift to Malaysia, it flourishes in tropical climate impacting every walk of life as an ingredient that is so necessary for not just food, feed, fuels and chemicals.

The oil produced, PO, provides many benefits for human health through decades of scientific research. In order to continuously expand and be relevant in the next 100 years, the oil palm industry and its stakeholders must stand united and collaborate across disciplines and industrial sectors, to readily showcase and develop more innovative and highly disruptive technologies at every level of the supply chain from upstream, midstream, to downstream processes. A blend of traditional sciences with new advancements in technology is desirably taking into account transformative and industrial revolutionary convergence which is essential for the whole industry to be at the forefront of these changes in meeting high-income status and sustainable development.

Yield enhancement via advanced breeding and tissue culture propagation in developing improved planting materials is at the core of the industry which is of utmost importance due to decade-long issues concerning stagnating yields, land scarcity, labour shortage and climate change, which collectively are a threat to the industry. These challenges together with environmental degradation, erratic weather patterns and rising fuel cost are seen as opportunities to improve crop yields. This is where the amalgamation of enabling technologies such as advanced computational systems integrating 'big data' information with high end detection components is changing the way to do things. We foresee a more concerted effort will be channelled to plant phenotyping to support the rapid development of plant genomics in realising the vision of a digital plantation in the future. Automation and mechanisation will be key in transforming the current plantation management into a more cost-efficient and modern entity. The use of cloud computing, advanced sensors, drones, robotics, *etc*., in developing efficient harvesting tools and providing necessary training are crucial in moving towards improved automation and mechanisation due to labour scarcity.

Flexibility in technology, process development and information utilisation to accommodate changes or align and generalise overall large-scale system operation is highly sought-after for high throughput screening in PO processing. Transforming the abundantly generated oil palm co-products along the supply chain through versatile biomass valorisation in creating a circular economy is seen a big leap for the oil palm industry to be at a competitive edge in the international arena in pursuing global sustainability, a goal increasing in popularity. Optimisation and diversification efforts will increasingly be emphasised due to resource scarcity. In the midst of increasing oil palm productivity, new innovative technologies within palm oil mills (*e.g*. a biorefinery), taking into account a multi-layered system approach coupled with smart government-private partnership are urged to drive the industry further for profitable and sustainable PO production.

Factual and robust information on PO nutrition were evidenced through extensive scientific research amid negative allegations against PO linking to various health issues. Moving forward, refining and fractionation of PO in the future need to take advantage of digital technology in producing niche PO specialty products featuring ready-to-eat, convenient and well-balanced nutrients, as well as smart and superfood formulation loaded with palm phytonutrients. Tailoring food to meet an individual's genetic make-up and lifestyle is desirable. As such, a customised or personalised palm-based food menu caters to individual optimum health benefits and caloric requirement based on lifestyle will be the goal.

The oleochemical segment contributes to almost every manufactured product. Thus, palm-based oleochemicals are well situated to play an increasingly greater role in the global oleochemical industry, impacting many markets such as agriculture, automotive, construction, household and consumer products, *etc.* Transforming the future palm-based oleochemicals will require collaboration between oleo- and petro-chemicals industries through transformative and new chemical, biochemical and catalytic technologies to boost the performances of the resulting individual ingredient/final products and enhance their bio-based content and environmental sustainability.

Another aspect is sustainability and certification of PO encompassing the three important socio-economic elements of planet, profit and people. Quality and food safety should not be compromised while continually promoting PO as a healthy oil globally. It is important to ensure that all palm-based products perform superiorly to meet specifications eligible for premium pricing. Holistically integrating all potential sub-processes or activities along the whole PO supply chain must be accomplished to ultimately maximise outputs, minimise waste and feedstock utilisation and propagate value-addition. Expanding data volumes across R&D ensures 'big data' generation, bringing the Internet of things (IoT) and 3D printing to the forefront in projecting the benefits and versatility of PO and its products. Effective communication with the help of IoT is to be accelerated in positioning the oil palm industry as a responsible global agriculture leader – in technology, innovation, and development throughout the PO supply chain.

CONCLUSION

The oil palm industry recorded substantial economic growth and R&D progress in 2017 globally in its current challenging landscapes. Emphasis is on yield improvement through biotechnological approach. Issues surrounding the oil palm industry pertaining to sustainability and the environment demand the industry to be on constant lookout for the latest advancements and technologies. Innovation-based development of the industry is the key to sustainable economic growth across its process chain. However, the direction it takes depends very much on industry's readiness in embracing these so-called transformations. It is evident, time and again, that by immersing in new technologies and employing them routinely both in research and field practices will expedite the transformation of the oil palm industry into a more resilient industry when facing the challenges of the future. Focus should now be directed at enhancing the upstream sector whilst balancing the midstream and downstream applications towards creating a new economic model for the oil palm industry by positioning it as one of the largest wealth-generating sectors.

ACKNOWLEDGEMENT

The authors wish to thank all from the different divisions at MPOB for their contribution to this article.

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