Journal of Oil Palm Research Vol. 36 (2) June 2024 p. 171-186
DOI: https://doi.org/10.21894/jopr.2024.0037

OIL PALM ECONOMIC PERFORMANCE IN MALAYSIA AND R&D PROGRESS IN 2023

GHULAM KADIR AHMAD PARVEEZ[1]*; SOON-SEN LEOW[1]; NUR NADIA KAMIL[1]; AHMAD ZAIRUN MADIHAH[1]; MAIZURA ITHNIN[1]; MEI HAN NG[1]; YUSRABBIL AMIYATI YUSOF[1] and ZAINAB IDRIS[1]

ABSTRACT

Malaysia is the second largest palm oil producer in the world. This review article highlights the performance of the industry in 2023 and the recent R&D progress throughout the entire supply chain. This is aimed at providing future directions for a resilient and sustainable oil palm industry. Crude palm oil (CPO) production increased slightly despite a slight decrease in planted area, due to a 1.9% rise in fresh fruit bunches (FFB) yield per hectare and a 0.8% improvement in oil extraction rate (OER). Challenges persisted, with a 3.9% decline in exports and an 8.1% increase in average closing stocks due to weakened global demand. Efforts to enhance upstream processes include integrated pest and disease management, and precision agriculture. Advancements in biotechnology research have continuously boosted oil yield and value, while the processing sector evolves to manage carbon emissions and utilise palm biomass more efficiently. The versatility of palm oil enables research on value addition in food and eco-friendly oleochemical products in the global markets. While the industry is recovering from the COVID-19 pandemic, technology advancement through R&D endeavours focused on leveraging artificial intelligence for plantation and milling management, as well as identifying novel genetic modifications and palm-based ingredients for improved applications, is warranted.

Keywords: food safety and nutrition, mechanisation and automation, sustainable development, value addition, yield performance.

Received: 5 March 2024; **Accepted:** 5 June 2024; **Published online:** 27 June 2024.

INTRODUCTION

The oil palm (*Elaeis guineensis*) is primarily cultivated for the production of palm oil, a major commodity in the global oils and fats market, accounting for a significant share of total production. The demand for palm oil is driven by its versatile applications in the food industries as well as non-food industries such as cosmetics and biofuels. The industry plays an important role in the economies of producing countries, providing employment opportunities and contributing to export earnings.

The oils and fats market is influenced by various factors, including consumer preferences, health and wellness trends, global economic conditions, as well as regulatory changes (Jinadasa *et al.*, 2022). At the outset of 2023, the global oils and fats market was characterised by a heightened sense of optimism, with prices of global oils and fats demonstrating a higher degree of stability in comparison to the previous year. This was primarily attributed to the gradual recovery from the repercussions of the COVID-19 pandemic. Nevertheless, while the industry forecasts for Malaysia's palm oil production were positive, persistent effects of labour shortage in the previous years had continued to exert adverse influence on the Malaysian palm oil sector, thereby impeding palm oil production growth in 2023 (MPOB, 2024).

According to Abubakar *et al.* (2023), addressing yield stagnation upstream is vital for efficient and sustainable palm oil production. Planting materials with low genetic potential for high yields may contribute to stagnation. Improved planting

[1] Malaysian Palm Oil Board,
6 Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.

* Corresponding author e-mail: parveez@mpob.gov.my

materials of high-yielding varieties are thus essential for maintaining or increasing productivity. As plantations age, the productivity may also decline, leading to lower yields. This decline is often attributed to factors such as reduced nutrient absorption and increased susceptibility to diseases. In addition, diseases and pest infestations could significantly impact oil yields. If not effectively managed, these issues could lead to a decline in productivity. Inadequate agricultural practices, including improper plant spacing, lack of timely fertilisation, as well as insufficient pest and disease control may contribute to yield stagnation. Continuous R&D is thus crucial for identifying new techniques, technologies and oil palm varieties that may enhance productivity sustainably. A holistic approach that includes sustainable agricultural practices, proper plantation management, as well as disease and pest control is essential. Additionally, efforts to promote sustainable and environmentally friendly practices may contribute to long-term productivity and overall viability of the industry.

Industrial Revolution 4.0 (IR 4.0) called for reduced labour dependency, which propelled the oil palm industry to venture into automation, especially in terms of reducing carbon footprint via the development of smart mills and sustainable aviation fuels (Lim *et al*., 2021). Various palm oil processing factors in the midstream sectors, such as milling and waste management, especially treatment of palm oil mill effluent, were also revolutionised to create a clean and modernised industry. Valorisation of oil palm by-products and palm oil derivatives further adds value by creating downstream products to generate a circular economy (Siagian *et al*., 2024). While perceptions related to food safety and nutrition of palm oil were generally not supported by only scientific rationale, addressing these perceptions remains crucial to safeguard the industry. Palm oil being a versatile and functional commodity is known to be an essential ingredient in food and feed formulations. In addition, the increasing demand for renewable and sustainable palm-based oleochemicals for non-food applications further creates opportunities for downstream value addition.

Malaysia, being the world's second-largest palm oil producer, has been a leader in oil palm R&D for over 100 years. To identify the relevant R&D works carried out in 2023, the literature review was conducted by searching for scientific journal papers related to oil palm, palm oil and Malaysia which were published in 2023. This review article thus, highlights the performance of the Malaysian palm oil industry in 2023 and the recent research progress and innovative developments throughout the entire supply chain to provide future directions for a resilient and sustainable oil palm industry.

PERFORMANCE OF THE MALAYSIAN OIL PALM INDUSTRY

In 2023, the Malaysian oil palm industry exhibited a considerably better performance compared to the preceding year. While a marginal reduction in the planted area was observed, crude palm oil (CPO) production experienced a slight uptick, signifying a measured growth in output. Enhanced efficiency in palm oil production was evident through an increase of 1.9% in fresh fruit bunches (FFB) yield per hectare and a 0.8% improvement in oil extraction rate (OER). However, the industry faced challenges, as reflected in a 3.9% decline in exports, attributable to diminished global demand. Notably, the average closing stocks in 2023 increased by 8.1%, signalling a reduction in inventory pressures. The industry's overall economic landscape was marked by a substantial 25.1% decrease in the average CPO price, resulting in a notable 23.9% decline in export revenues.

Oil Palm Planted Area

The Malaysian oil palm planted area as of December 2023 declined marginally by 0.4% to 5.65 million hectares from 5.67 million hectares in December 2022. This reduction in the planted area was partly attributed to ongoing site preparation activities for replanting initiatives within the industry. Notably, certain estates had proactively undertaken the removal of old or unproductive oil palm trees in anticipation of replanting. As a result, these specific areas, where trees were cut down, were intentionally excluded from the total hectare count for oil palm planted area. This strategic approach of clearing unproductive trees underscores the industry's commitment to maintaining sustainable practices and optimising productivity by replacing ageing plantations with more productive and resilient oil palm crops. Examining regional performances revealed a reduction of 0.39% year-on-year in the planted area of oil palm in Malaysia. Specifically, there was a year-on-year decline of 1.00% in the oil palm planted area in Peninsular Malaysia. In contrast, Sabah and Sarawak experienced expansions in oil palm planted area, with growth rates of 0.13% and 0.08%, respectively. Unlike the trends observed in the planted area, the matured area for oil palm in Malaysia witnessed a marginal increase of 0.06% year-on-year in 2023. This matured area encompassed 5.13 million hectares, constituting 90.8% of the total oil palm planted area in Malaysia for 2023. Notably, Sarawak contributed significantly to the overall growth in matured area, demonstrating a substantial year-on-year increase of 1.17%. Conversely, the matured area contracted in Peninsular Malaysia and Sabah by 0.17% and 0.80%, respectively (*Table 1*). In terms of holdings, 73.6% of the planted area was owned by private and government state agency estates, 14.5% was owned by independent smallholders and the remainder of 11.9% was owned by organised smallholders (*Figure 1*).

CPO Production and Oil Palm Productivity

Despite encountering a marginal reduction in the planted area, the Malaysian oil palm industry demonstrated a modest increase in CPO production. Specifically, CPO production for 2023 experienced a 0.5% increment, reaching 18.55 million tonnes compared to the 18.45 million tonnes recorded in 2022. This marginal enhancement was attributed to an improved labour supply, particularly in key roles such as harvesters and FFB collectors. The improvement in labour supply instilled a positive sentiment for the Malaysian oil palm plantation sector. However, in 2023, the enduring effects of the acute labour shortage experienced in 2022 extended up to at least the first half of the year. The freeze imposed by the government on hiring foreign workers from 2020 to 2022, resulted in a substantial deficit of about 50 000 workers in the oil palm plantation sector (Ismail and Kamil, 2023). Although the subsequent lifting of the freeze offered some relief, the industry continued to contend with the lasting repercussions of this labour challenge. This shortage not only affected harvesting exercises but also impacted other operational activities such as pruning and manuring, thus explaining the subtle growth observed in CPO production for the year 2023. In parallel with the challenges faced by CPO production, the performance of FFB yield in 2023 is of particular significance, given its direct impact on the overall CPO production process. Despite the improvement in labour supply during the year, the Malaysian oil palm estate average FFB yield in 2023 improved merely by 1.9% to 15.79 t ha^{-1} from 15.49 t ha^{-1} in 2022. The growth in FFB yield was constrained by the lingering effects of the acute labour shortage. Other than FFB yield, OER is also important in determining CPO production. In 2023, the average OER was recorded at 19.86%, slightly higher than the previous rate of 19.70% in 2022, but slightly lower than the average 5-year OER of 19.96%.

Trade Performances of Palm Oil and Other Palm-based Products (POPP)

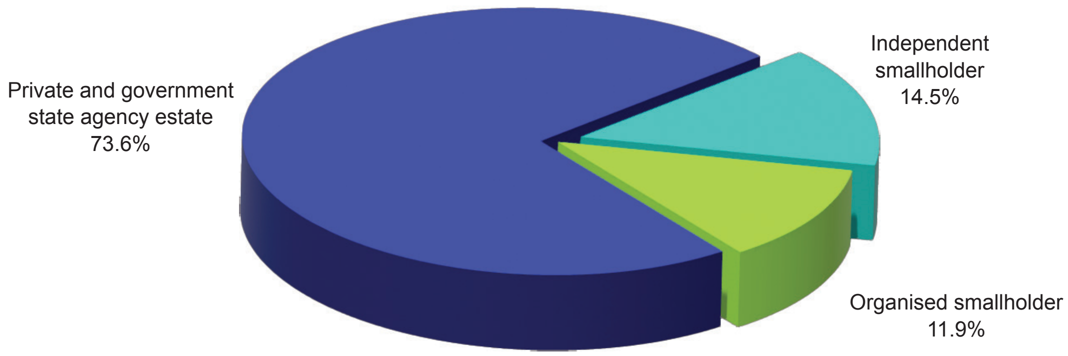
Overall, the export performance of POPP in 2023 witnessed a decline, primarily attributed to reduced demand from Malaysia's major importing countries. Exports of palm oil and palm kernel oil in 2023, which represented 65.8% of the total POPP exports, declined by 3.7% and 5.0% year-on-year, respectively (*Table 2*). These declines were mainly due to lower imports by the major buyers of Malaysian palm oil, such as China, India and the European Union (EU).

TABLE 1. MALAYSIAN OIL PALM AREA (ha) IN 2023

Item	Planted area			Matured area		
	2023	2022	Difference (%)	2023	2022	Difference (%)
Peninsular Malaysia	2 518 883	2 544 307	-1.00	2 307 546	2 311 432	-0.17
Sabah	1 510 025	1 508 060	0.13	1 316 356	1 326 940	-0.80
Sarawak	1 623 661	1 622 374	0.08	1 506 271	1 488 917	1.17
Malaysia*	5 652 569	5 674 742	-0.39	5 130 172	5 127 290	0.06

Note: *The figures have been rounded to the nearest whole number. Percentage has been calculated based on full figure.

Source: MPOB (2024).



Source: MPOB (2024).

Figure 1. Oil palm planted area in 2023 by holdings.

In 2023, India's import of Malaysian palm oil witnessed a marginal decline of 1.6% year-on-year, totalling 2.84 million tonnes. This decline could be attributed to the shift in India's palm oil market dynamics. In 2023, imports of Indonesian palm oil by India increased by 7.0% to 5.56 million tonnes compared to the 5.20 million tonnes recorded in 2022 (MPOB, 2024; Oil World, 2024).

Meanwhile, exports of Malaysian palm oil to China declined by 16.8%, amounting to 1.47 million tonnes. This reduction could also be explained by the substantial surge in palm oil imports from Indonesia, which increased by 30.7% to 5.06 million tonnes in 2023, as compared to 3.87 million tonnes in the corresponding period of 2022. The shift in market preference from Malaysia to Indonesia by India and China can be primarily attributed to the reduced premium of Indonesian CPO prices as compared to Malaysian CPO prices. The diminished premium of Indonesian CPO prices in 2023 against that of 2022, likely influenced international buyers to reassess their market preferences. With Indonesia offering palm oil at more appealing prices, buyers were incentivised to shift their purchases towards Indonesian CPO, leading to a reduction of market share for Malaysia. Other than CPO price differential between Indonesia and Malaysia, the higher intake of soybeans for crushing activities from Brazil by 11.7% to 101.73 million tonnes in 2023, played a role in filling up the oils and fats demand gap in China. Consequently, this increased soybean intake contributed to a decreased demand for palm oil from Malaysia (MPOB, 2024; Oil World, 2024).

Palm oil exports to the EU in 2023 declined by 27.6% to 1.07 million tonnes as compared to 1.47 million tonnes in the same period last year. This was due to ample supply of domestic vegetable oils in view of higher crushing activities of major oilseeds such as soybean, sunflower seed, and rapeseed, by 5.1% to 38.84 million tonnes in 2023 from 36.95 million tonnes in 2022 (MPOB, 2024; Oil World, 2024).

The total export values of POPP experienced a contraction by 27.1%, declining to RM94.95 billion in 2023 from the previously earned RM130.22 billion in 2022. Specifically, the export value pertaining to palm oil amounted to RM62.58 billion, thus reflecting a decline of RM23.89 billion (27.6%) from the RM86.47 billion recorded in 2022 (MPOB, 2024). This reduction is attributed to the lower export volume and lower prices of palm oil products within the global vegetable oils market.

The volume of palm oil imported in 2023 amounted to 898 806 t, thus reflecting a notable decline of 21.1% as compared to the figures recorded in 2022. This reduction in imports can be attributed to the higher domestic production of palm oil by 0.5% or 98 530 t, coupled with the reduced export of palm oil by 3.7% or 581 334 t (MPOB, 2024).

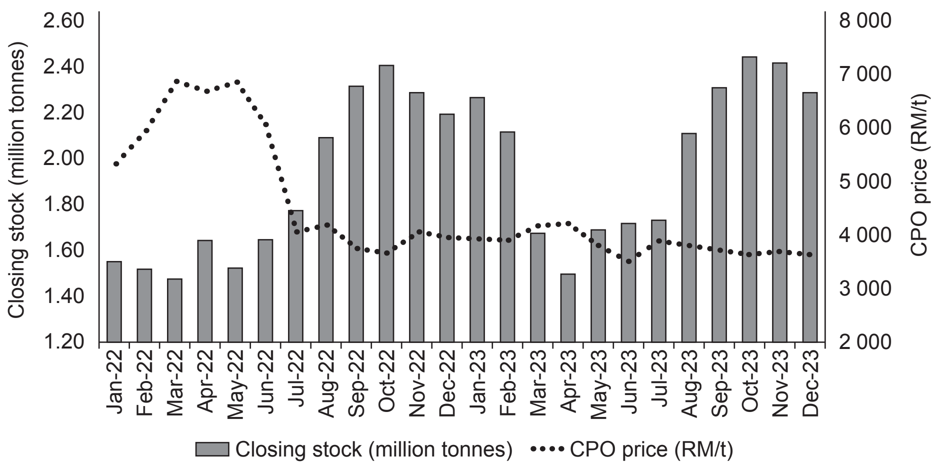
Palm Oil Stocks and Prices

In 2023, the average monthly palm oil stock demonstrated a notable increase, rising by 8.1% to an average of 2.02 million tonnes in comparison to the 1.87 million tonnes recorded in 2022. This upturn in the average monthly stock could be attributed to enhancements in CPO production, coupled with reduced uptake from key buyers of Malaysian palm oil. The combined effects of improved production and decreased demand contributed to the overall elevation in the monthly palm oil stock levels throughout 2023. The easing of stock conditions compared to the preceding year had a softening effect on CPO prices throughout 2023, with the average price decreasing by 25.1% to RM3809.50 t^{-1}, in contrast to the recorded RM5087.50 t^{-1} in 2022 (*Figure 2*). It is worthy to note that the price gap dynamics between Malaysia and Indonesia. In 2023, an optimistic trend emerged as the price gap between Indonesia's CPO Freight on Board (FOB) and Malaysia's CPO FOB narrowed (*Figure 3*).

TABLE 2. MALAYSIAN EXPORTS OF PALM OIL AND OIL PALM PRODUCTS

Item	Volume (t)			Value (RM million)		
	2023	2022	Difference (%)	2023	2022	Difference (%)
Palm oil	15 130 738	15 712 071	-3.7	62 584.10	86 471.91	-27.6
Palm kernel oil	981 799	1 033 850	-5.0	4 993.09	8 345.72	-40.2
Palm-based oleochemicals	2 864 004	2 734 203	4.8	15 998.82	22 875.07	-30.1
Biodiesel	244 793	309 374	-20.9	1 310.49	2 068.74	-36.7
Finished products	527 063	561 245	-6.1	3 602.05	4 389.23	-17.9
Palm kernel cake	2 311 506	2 146 024	7.7	1 667.21	1 669.92	-0.2
Other oil palm products	2 427 193	2 216 375	9.5	4 793.20	4 403.51	8.9
Total	**24 487 095**	**24 713 142**	**-0.9**	**94 948.96**	**130 224.10**	**-27.1**

Source: MPOB (2024).



Source: MPOB (2024).

Figure 2. Closing stocks and CPO prices from January 2022 to December 2023.

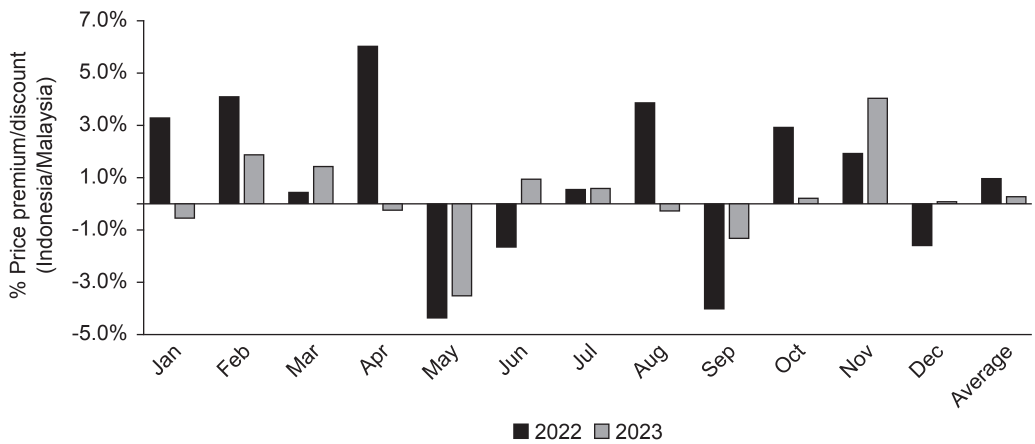


Figure 3. CPO price differentials between Indonesia over Malaysia (%).

Throughout 2022, the CPO price in Indonesia was consistently higher than that in Malaysia, occasionally offering discounts. These fluctuations were noticeable on a monthly basis, with Indonesia's premiums or discounts compared to those of Malaysia varying significantly. The year began with Indonesia commanding a 3.8% premium in January, peaking at 6.2% in April, before transitioning to a 2.6% discount by June. Despite these fluctuations, Indonesia maintained an average premium of 1.0% over Malaysia in 2022. However, the subsequent year saw a significant shift in market dynamics, characterised by a more balanced distribution of discounts and premiums between the two producing countries. The persistent trend of price fluctuations throughout 2023 resulted in a reduced average price premium of only 0.3% by year-end. The reduced premium of Indonesian CPO price over Malaysian CPO price in 2023 likely caused a shift in market preferences, leading to an increase in the quantity demanded of Indonesian palm oil compared to Malaysian palm oil. This shift aligns with the Law of Demand, as buyers tend to favour goods that are more economically advantageous.

Overall, the Malaysian oil palm industry in 2023 experienced a balanced growth trajectory. Despite a moderate increase in CPO production, the industry maintained a stable momentum. Although palm oil exports experienced a decline, this was largely attributed to temporary factors, such as lower uptakes from major importing countries. On a positive note, palm oil imports were reduced, in relation to an increase in stock levels. This strategic adjustment in stock positions not only enhances market stability but also positions the industry well for future demand. The resulting softening of CPO prices can be viewed as a proactive and adaptive measure, thus showcasing the industry's resilience in navigating market dynamics.

R&D FOCUS AREAS IN 2023

Improving Oil Palm Yield Performance Sustainably

The progressive research achievement in developing new planting materials is aimed at increasing productivity, reducing the cost of harvesting, and improving tolerance to diseases. Agriculture performance especially oil palm cultivation is severely impacted by climate change phenomena such as *La Niña* and *El Niño* (Paterson, 2023). Yield patterns revealed a decline in FFB and hence CPO production during *El Niño*, and long-term effects can be seen as the unusually warm and hot weather which causes less rainfall and more stress to oil palm (Khor *et al.*, 2023). Meanwhile, during *La Niña*, heavy rainfall leads to floods, which affect harvesting and collection of FFB in plantations of low-lying areas.

In Malaysia, the land suitable for oil palm plantation expansion is limited and scarce, thus keeping the yield stagnant or below potential. Peatlands provide richness in methanotrophs (methane consumers) and methanogens (methane producers), with the upper peat layers demonstrating biogeochemical processes linked to methane production, thus providing valuable insights in predicting methane emissions from cultivation of oil palm on peat (Ayob *et al.*, 2023). A study by McCalmont *et al.* (2023) showed that present peat drainage levels may be limiting palm photosynthetic uptake and water tables shallower than industry standards may be more optimal for yields. Taking into consideration the need to reduce gas emissions, more extensive research is needed to confirm and further verify these findings. Other implications of cultivation on peatlands are peat soil subsidence, drainage of peatlands associated with flooding, peat oxidation with susceptibility to fire and productivity loss. Many studies have suggested the implementation of activities such as proper management of cultivation on peat soil, improvement of land use and spatial planning, sustainable forest management, rehabilitation of degraded ecosystems, as well as setting aside part of landbanks for nature conservation to alleviate the impact of emissions on biodiversity loss (Harahap *et al.*, 2023).

Bicknell *et al.* (2023) revealed that the best practice to sustain oil palm cultivation, especially in peat areas, is the set-aside approach alongside rivers, which is practically done on a spatially targeted and variable basis among plantations without reducing the cultivation net area. Amit *et al.* (2023) demonstrated that oil palm agriculture combined with the set-aside strategy in peat swamp forests and riparian reserves preserved a high percentage of canopies and shrub covers, hence improving the conservation of tropical biodiversity and promoting richness of bird species. Enhancing tree species diversity and the complexity of vegetation could preserve the heterogeneity of canopy openness, whilst intensifying ecosystem dynamics and habitat diversity (Li *et al.*, 2023). An alternative cropping system with a combination of various crops in oil palm plots, thus converting monoculture to oil palm-based agroforestry systems, offers a new perspective for sustainable palm oil production (Masure *et al.*, 2023). Oil palm planting on peat can be done sustainably with improved peat planting technology, a better understanding of peat features and optimum agro-management techniques.

The Government of Malaysia is committed to promoting the adoption of Good Agricultural Practices (GAPS) through Malaysian Sustainable Palm Oil (MSPO) certification which evidently improved FFB production and positively influenced the efficiency and well-being of independent smallholders (Mohd Suib *et al.*, 2023). MSPO aids smallholders in a multitude of ways, which include providing financial and technical support, advisory services, health and safety at work, human rights, and income generation. In the long run, issues and challenges regarding MSPO certification should be dynamically identified along the supply chain to improve relevant policies from time to time and to ensure that the contributions by smallholders continue to remain relevant (Siti-Dina *et al.*, 2023).

Despite the diligence given to environmental impact, socioeconomics received less attention from the public and in research. Nevertheless, Sibhatu (2023) demonstrated significant improvements in economies of both non-producing and producing countries, facilitated by exports of CPO and its products, as well as through the provision of job opportunities. Therefore, the oil palm industry has successfully stimulated economic development in rural areas, further alleviating rural poverty (SDG 1) improving food security (SDG 2), thus leading to better health (SDG 3) and economic stability (SDG 8), in accordance to Sustainable Development Goals (SDGS).

The oil palm industry continued to explore many innovative approaches to combat infestations of pests and diseases in oil palm plantations. The devastating infestations by *Pteroma pendula*, *Metisa plana* and *Mahasena corbetti* (Lepidoptera: Psychidae), the three psychid bagworm species, are causing serious economic impacts on palm oil production. Recurring infestations still occur due to the lack of understanding of the pests' adaptation towards insecticides, hence addressing this knowledge gap is necessary. A molecular approach using transcriptome analysis through *de novo* assembly of *M. plana* revealed 6632 unigenes associated with insecticide detoxification and insecticide target modification (Zainuddin *et al.*, 2023). *Metisa plana* easily spreads due to mismanagement and low surveillance monitoring in the infested areas. A study by Napiah *et al.* (2023) showed that *M. plana* was minimally affected by changes in environmental conditions such as temperature, humidity, and rainfall. A study by Syarif *et al.* (2023) on *P. pendula* revealed that an entomopathogenic fungus identified as *Cordyceps javanica* BSB01, a potential eco-friendly biocontrol agent, achieved an LT_{50} of 6.76 days, being the shortest lethal time in comparison to other isolates. Another bagworm species, *M. corbetti* Tams, was identified by molecular and morphological methods and can be biologically controlled by *Bacillus thuringiensis* (MPOB Bt1), with 100% mortality of the *M. corbetti* larvae achieved by the third day after application (Maidin *et al.*, 2023). The use of *Turnera subulata*, a beneficial plant, to attract bagworm's natural enemy, *Chalchidae* has been successfully demonstrated as a potential alternative to chemical pesticides in oil palm plantations (Ahmad *et al.*, 2023). Bakeri *et al.* (2023) also demonstrated that *Oryctes* Nudivirus (OrNV) applied on pheromone traps could be used as a biocontrol agent to combat *Oryctes rhinoceros*, another pest of the oil palm. Pest management strategies using natural predators such as mammals, birds and arthropods were successfully examined and positively correlated with an increase in understorey vegetative coverage and hence reduced dependency on chemical usage in controlling pests in oil palm plantations (Denan *et al.*, 2023).

Zulkefli *et al.* (2023) studied the nutritional composition of the anthesising male inflorescence (AMI) of oil palm as the feeding and breeding ground for *Elaeidobius kamerunicus*, the most effective pollinator of oil palm. Hence, understanding nutritional composition of AMI could help in the effective rearing of the pollinator. AMI reportedly contains high moisture content, followed by carbohydrates, protein, fat, and ash. The highest macronutrient contents recorded are 18 amino acids, with lysine being the highest at 14%, and 32 fatty acids, with oleic acid being the highest at 43%, thus serving as feeding and breeding ground for the pollinator.

The phytopathogenic fungus *Ganoderma boninense* causes losses to oil palm industry of up to USD500 million a year (Zakaria, 2023). Lo *et al.* (2023) reported that the *Ganoderma* white-rot fungus isolated from Sarawak, Malaysia, could be classified into different aggressiveness categories. The most aggressive isolate found in this study is known as *G. boninense* 5B, which can eventually cause seedling mortality. Genes and metabolic pathways that respond during oil palm's defence against *G. boninense* infections could potentially be utilised as markers for disease detection (Zakaria, 2023). In another study, the *G. boninense* isolate ET61 was determined to be the most aggressive among the species tested and showed the highest ligninolytic activity (lignin peroxidase, manganese peroxidase and laccase) on day 80 across other isolates. An investigation of macronutrient requirements proved that potassium was crucial for *G. boninense* growth, causing suppression of radial growth when a low amount was applied (Periasamy *et al.*, 2023). Detection of *G. boninense* using conventional ground-based detection is costly and laborious. Consequently, the development of airborne hyperspectral remote sensing technology coupled with ground detection offers an effective option (Izzuddin *et al.*, 2023). Application of Savitzky-Golay and wavelet spectral denoising techniques have improved the quality of hyperspectral data and signatures for *G. boninense* detection. Adoption of remote sensing technology among smallholders, state-owned plantations and private plantations alike will be extremely useful towards empowering the oil palm industry (Diana and Farida, 2023).

Integrated disease management using biocontrol agents such as fungi and endophytic bacteria has been proven to effectively combat basal stem rot (BSR) disease. Darlis *et al.* (2023) and Naidu *et al.* (2023) claimed that polypore fungi *Fomes* sp. (SRP11), *Trametes lactinea* (SRP18) and *Trametes elegans* (SRP17) showed percentage radial growth inhibition of *G. boninense*. Naidu *et al.* (2023) studied wood-degrading organisms, specifically *Lentinus tigrinus* FBJG3, *Trametes lactinea* FBW and *Clitopilus prunulus* ST3, and revealed that they might be able to accelerate the degradation of diseased palms. Chemical changes were observed during pre-treatment, suggesting that *L. tigrinus* attacks S-lignin, while *T. lactinea* strikes G-lignin, thus producing significant amounts of laccase.

Pseudomonas aeruginosa encapsulated with calcium carbonate microshells and coated with sodium alginate with the combination of skim milk and empty fruit bunch, has also been tested as a green-technology formulation to biocontrol *G. boninense*. Encapsulated bacteria survived for 17 months at 4°C conditions, maintaining a percentage radial growth inhibition of 70% *G. boninense* and sustained viability at 1×10^6 colony formation unit mL^{-1} after three months of storage, thus indicating that the coated alginate offered better results for the control of *G. boninense* in comparison to free bacterial cells (Mustafa *et al.*, 2023). The combination of biostimulants and biocontrol agents revealed synergistic effects in reducing biotic and abiotic pressures of plants, thus simultaneously improving crop yield and growth (Anuar *et al.*, 2023). Approaches to integrated *Ganoderma* management are being imposed using various strategies which aim to reduce the incidences of BSR in oil palm plantations (Khoo and Chong, 2023).

Studies on weeds in oil palm plantations are important for pest management. To date, weed management is highly dependent on herbicides and might have adverse effects on the oil palm. As an alternative to reduce herbicide usage in oil palm plantations, a fungal isolate identified as *Bipolaris sorokiniana* showed effectiveness in controlling goosegrasses (*Eleusine indica*), hence having the potential to be used as a bioherbicide in plantations to minimise the occurrence of weed resistance (Ismail *et al.*, 2023a). Short- and long-term income sources can also be generated simultaneously by adopting livestock integration through rotating small multi-species grazing ruminants such as sheep and goats in different cycles, suppressing undesired weeds such as woody broadleaves and practically producing oil palm silvopastoral systems (Tohiran *et al.*, 2023).

Biotechnology Tools for Oil Palm Improvement

Understanding plant molecular mechanisms is undoubtedly crucial in the effort to develop new oil palm planting materials. The knowledge gained can accelerate the identification of key genes linked to economically important traits, which could be rapidly and efficiently applied in crop breeding and genetic engineering programmes. In the oil palm, these technologies are being progressively applied to improve oil yield, productivity, and tolerance to *Ganoderma*.

The oil palm yield performance is conventionally improved by evaluating the Deli *dura* breeding populations, the common source of female parents used for commercial seed production. Based on bunch quality and bunch yield components, some introgressed progenies were identified as the most promising *dura* progeny at individual palm level for commercial oil palm seed production, as well as being a genetic source to further improve the *dura* breeding lines (Abdullah *et al.*, 2023). The use of DNA tests via 'SHELL genetic testing', enables identification and exclusion of lower yielding non-*tenera* palms from commercial plantings (Ooi *et al.*, 2023; Singh *et al.*, 2022). The vigour of pure D×P *tenera* hybrids can therefore be fully exploited, leading to increased yields on existing land allocated for commercial oil palms. Coupled with Mate Selection (MS), Tchounke *et al.* (2023) applied genomic selection (GS) in oil palm where preferential candidate parents are selected and mates are allocated simultaneously to realise optimal annual genetic progress. Negative consequences of inbreeding such as the loss of favourable alleles and expression of detrimental recessive mutations could also be avoided when incorporating MS in GS.

Researchers in Southeast Asia are exploring the development of *Ganoderma* tolerant varieties of oil palm by investigating oil palm-*Ganoderma* interactions via genetic engineering approaches. A number of proteins and pathways that appear to be related to pathogenic species of *Ganoderma* through the analysis of secretome profiles revealed that two carbohydrate-active enzymes (CAZymes), namely formate dehydrogenase and superoxide dismutase, are potentially associated with *G. boninense* pathogenicity (Dzulkafli *et al.*, 2023).

A study by Shokrollahi *et al.* (2023) revealed that isonicotinic acid (INA), azelaic acid (AzA), ricinoleic acid (RA) and another 51 bioactive compounds acted as plant defence inducers. In addition, Santiago *et al.* (2023) ranked 15 important plant-derived secondary metabolites that are increased (fatty acids 11-hydroperoxy-12,13-epoxy-9-octadecenoic acid and 9-hydroxy-hexadecan-1,16-dioic acid) and decreased (5,7,4′-trihydroxy-3,6,8,3′,5′-pentamethoxyflavone, kanokoside A and kakuol) in the presence of *G. boninense*. Additional metabolomics profiling also showed that choline phosphate and 2-oxoglutaramate were present in crude rachis extracts of *G. boninense*-infected oil palms but absent in healthy palms (Baharum *et al.*, 2023). A non-destructive diagnostic assay can be developed from these biomarkers for early detection of oil palm *Ganoderma* infection. Mohan *et al.* (2022) analysed the expression of selected genes in oil palm roots infected by *G. boninense* at multiple time points, which revealed the effects of salicylic acid at the early stage and that jasmonic acid-mediated defence response was activated at the later infection stage.

Recently, Fizree *et al.* (2023) developed an optimised technique to deliver nucleic acid into oil palm protoplast. This polyethylene glycol (PEG)-mediated transformation protocol recorded as high as 56% transformation efficiency in delivering genes into oil palm protoplast. The presence of specific motifs is crucial in determining tissue specific promoters' strength and specificity in driving successful expression of the transgenes. The two mesocarp specific promoters namely, MSP2-GLG and MSP2-GLC, isolated through genetic engineering and RNAi technologies were transformed into *Arabidopsis.* The histochemical GUS staining confirmed their specific expression in flowers (Wahab *et al.*, 2023).

Lanosterol 14α-demethylase gene (ERG11) encodes for an important enzyme in ergosterol biosynthesis pathway in fungi and without it, the survival of fungi is affected. Thus, this enzyme could be the target for controlling fungal-related diseases. Lim *et al*. (2023) isolated the ERG11 gene from *G. boninense*. *In vitro* inoculation study of this gene revealed 2-fold higher expression in *G. boninense* during interaction with oil palm plantlets leading to an effective protection of oil palm against *Ganoderma* attack and hence opening the possibility to develop transgenic oil palms which are tolerant to *Ganoderma*.

Contribution of Oil Palm Towards Decarbonisation

The Council of Palm Oil Producing Countries (CPOPC), headed by Indonesia and Malaysia, asserted that the sector is progressing towards achieving net zero greenhouse gas (GHG) emissions with certain experts within the industry being optimistic that this objective could be attained by 2040, a full 10 years ahead of the United Nation's designated timeline (China Dialogue, 2023). Facilities to trap biogas from palm oil mills provide huge savings while efficiently address GHG emissions from mills. The history of biogas development in the oil palm industry dates back to the early 1980s.

As of 2021, there were 451 operational palm oil mills across the nation, with 135 mills equipped with biogas trapping facilities, *i.e.*, ~30% national biogas implementation (Nasrin *et al.*, 2023). The captured biogas normally consists of 60% to 70% methane (CH_4), 30% to 40% carbon dioxide (CO_2) and trace amount of hydrogen sulphide (H_2S) (Loh *et al.*, 2020). If all mills were to capture biogas and turn it into usable products, a huge technical potential could be achieved in terms of energy (MJ), diesel equivalent (L), natural gas equivalent (MMBTU), combined heat and power, bioelectricity (MWhr), and lastly national renewable energy (RE) installed capacity mix and RE share. This mitigation effort has the capability to capture ~247 988 t yr^{-1} methane from POME, and has thus contributed to about 33.1% GHG emission savings of 5.62 million tonnes of CO_2 eq. yr^{-1} computed based on electricity generation from the total biogas emitted nationwide.

The captured biogas can be used in many different applications, such as electricity generation either for grid connection or off-grid utilisation for downstream activities in close proximity to a palm oil mill or a palm oil refinery, biogas for co-firing or combined heat and power (CHP), as well as biogas for rural electrification and off-site utilisation (Loh *et al.*, 2020).

Fine Chemicals and Phytonutrients from Palm Biomass

The traditional practice of shredding and mulching harvested oil palm trunks (OPT) in fields creates favourable conditions for the proliferation of pests, thus necessitating the exploration of alternatives to unlock the untapped potential of underutilised OPT. The extraction of succinic acid (SA) presents a promising viable approach to diversify the use of OPT (Bukhari, 2023).

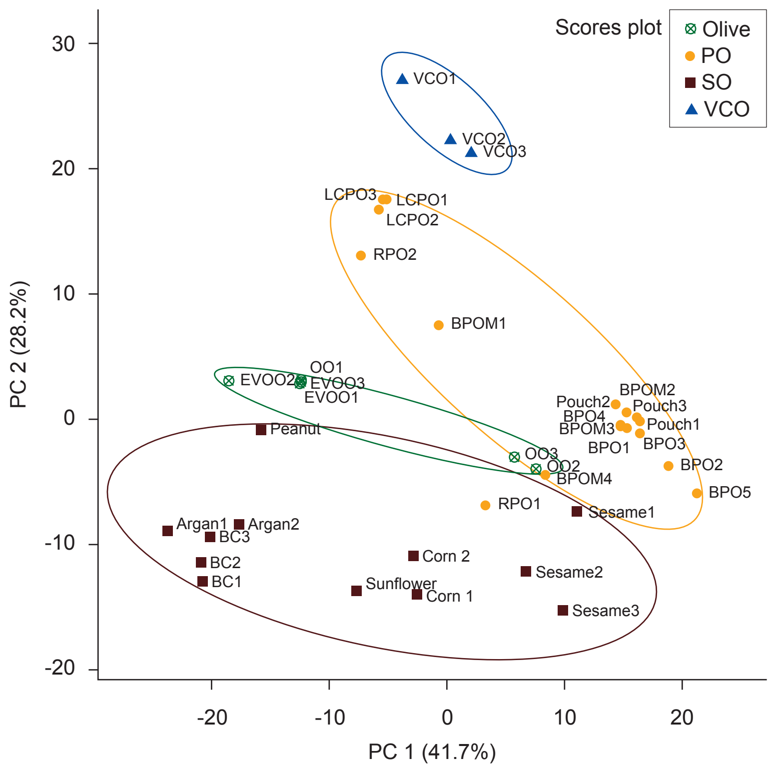
Palm pressed fibre is a potential source of red palm-pressed mesocarp olein which contains various phytonutrients. The half-life of vitamin E and carotenoid in red palm-pressed mesocarp olein are 21.6 months and 40.8 months respectively under the storage condition of 23°C in amber bottles, thus indicating that storage of this olein at lower temperatures and in light-limited environment could potentially prolong its shelf life (Teh *et al.*, 2023). An assessment of storage condition impact on the phytonutrient stability between red palm-pressed mesocarp olein and another three edible oils, *i.e.*, palm olein, sunflower oil and extra virgin olive oil under the same conditions again confirmed that storage at ambient temperature and dark conditions contributed to the best phytonutrient retention and oil quality (Teh and Lau, 2023).

In addition, ferulic acid, which is a phenolic acid with antioxidant and anti-ageing properties, can be extracted from various parts of the oil palm, including fruitlets, fronds, empty fruit bunches and palm pressed fibre by way of solvent extraction. Acetic acid was a better hydrogen bond donor compared to citric acid when tested with the choline chloride deep eutectic solvent (DES) for ferulic acid extraction from oil palm fruitlets (Ng and Nu'man, 2023).

Food Safety, Quality and Nutrition

The Malaysian palm oil industry prioritises food safety, quality and nutritional benefits of our edible oils and fats both for domestic consumption and export. Sources of adulteration and process contamination are continuously being investigated and mitigated to ensure compliance with regulatory requirements by the authorities. Various methods have been developed, validated, and verified to ensure their robustness. Gas chromatography-mass spectrometry (GC-MS) techniques combined with chemometrics and machine learning were successfully developed to detect adulteration using n-alkane profiles. Tetracosane (C24) and octadecane (C18) were the main n-alkane markers for differentiating lard from vegetable oils (Sapian *et al.*, 2023). Tahir *et al.* (2023) investigated triacylglycerol (TAG) composition of commercial palm cooking oils in different packagings and of different blends using proton nuclear magnetic resonance ^{1}H NMR spectroscopy combined with chemometrics. Laboratory-prepared palm oils were found to be closely linked to virgin coconut oils (*Figure 4*).

Mahiran *et al.* (2023) recently studied the level at which glycidol, used as a food flavouring, is categorised as a probable carcinogen. R- and S-glycidol potentially caused oxidative stress and affected extracellular signal-regulated kinase (ERK) protein phosphorylation, leading to caspase-3



Note: Olive - olive and extra virgin olive oils; PO - palm oil; SO - seed oils; VCO - virgin coconut oil; BC - black caraway seed oil; BPO - bottled palm cooking oil; BPOM - bottled palm cooking oil with unknown blend % of peanut and sesame oils; EVOO - extra virgin olive oil; LCPO - crude palm oil from plantation fresh fruit bunches; OO - olive oil; RPO - red palm oil.

Source: Tahir *et al.* (2023).

Figure 4. Principal component analysis plot of the ^{1}H NMR data of plant oils.

independent cell death of treated HCT 116 cells, thus, implying that lower doses of <1.16 µg mL^{-1} of R- and S-glycidol are safe for human consumption. Nevertheless, the possible presence of esters of 2- and 3-monochloropropanediol (2- and 3-MCPDE) and glycidol (GE) in infant formula products were investigated on 16 infant formulas in the Malaysian market using GC-MS. Only one formula related to GE exposure is potentially risky for children ages 0 to 5 months and 6 to 12 months, with a margin of exposure value below 25 000 (Nik Azmi *et al.*, 2023).

Chlorides are the main precursors for 2-MCPDE and 3-MCPDE formation during the processing of edible oils and hence methods to detect and quantify the amounts of chlorides present are crucial. Ng *et al.* (2023) developed and validated a detection and quantification method of organochlorine in CPO, palm superolein, refined sunflower oil and refined olive oil using quantitative NMR (qNMR). Ramli *et al.* (2023a) established an indirect analysis of GE, 2-MCPDE and 3-MCPDE in refined palm glycerol utilising GC-MS based on the AOCS Official Method Cd 29a-13 with modification. In addition, Ramli *et al.* (2023b) established the indirect analysis of these contaminants in fatty acids produced from oil splitting.

Palm Oil and Its Phytonutrients

Various pre-clinical and clinical studies demonstrated the benefits of Palm Tocotrienol-Rich Fraction (TRF). A meta-analysis of 10 studies from inception until March 2023 examined changes in blood pressure, HbA1c (glycated haemoglobin) and serum Hs-CRP (high sensitivity C-reactive protein) levels post-TRF supplementation in randomised controlled trials involving patients with type 2 diabetes mellitus (T2DM). TRF supplementation at doses of 250 to 400 mg significantly reduced HbA1c, particularly in six months interventions and where T2DM duration is less than 10 years. No significant reductions in blood pressure as well as serum Hs-CRP were found (Phang *et al.*, 2023). Diabetic retinopathy is the second most common T2DM microvascular complication. Twelve weeks of oral TRF gavage at 100 mg kg^{-1} body weight once daily preserved the retinal layer thickness and retinal venous diameter in streptozotocin-induced diabetic rats, as well as suppressed the expression of retinal inflammatory and angiogenic markers (Sadikan *et al.*, 2023). In addition, oral TRF reduced the expression of retinal angiogenic markers protein kinase C (PKC) and angiopoietin-2 (Ang-2) in these diabetic rats (Abdul Ghani *et al.*, 2023).

The effects of oral TRF on vascular dementia were investigated on rats induced with aluminium chloride (150 mg kg^{-1}) intraperitoneally for seven days. TRF treatment for 21 days significantly increased serum nitrite, expressed platelet-derived growth factor-C for the neovascularisation process in the hippocampus, decreased myeloperoxidase and thiobarbituric acid reactive substances, as well as improved memory (Shaikh and Muthuraman, 2023).

Product Development Efforts Towards Value Addition in Food and Feed Research

Fractionation, oleogelation and interesterification are among the various methods to process vegetable oils into value-added food grade ingredients or semi-finished food products. Palm olein can be further fractionated to produce palm superolein with iodine values of 60 and above, which is able to withstand lower temperatures before it clouds or solidifies. Oleogels which form a structured liquid organic phase in a three-dimensional network could be used to form stable superolein entrapments (Saw *et al.*, 2023). A study by Hassim *et al.* (2023) revealed the best compositions of carnauba wax and sunflower wax as structuring agents to form palm superolein blend oleogels.

New palm-based food applications which incorporate palm oil into their formulations have also been developed. Cheese analogue is made with dairy, partial dairy, or non-dairy ingredients, with milk fats or proteins substituted with vegetable fats and oils. Palm-based mozzarella cheese analogue with the incorporation of 100% palm oil blends provides superior quality, functionality, and sensory scores as a pizza cheese topping. It is also cost-effective to produce as its processing time is shorter (Ismail *et al.*, 2023b). In addition, Faridah *et al.* (2023) showed that palm shortenings with a melting range of 55°C to 60°C have the potential to replace chicken skin in the production of meat emulsions such as bologna, frankfurters, sausages and meatloaf. A higher melting temperature would cause products to be hard, while a lower melting temperature would result in weak emulsion stability, thus causing poor texture.

The acceptance of feed materials by animals is influenced by their quality. Fish oil is commonly used as a source of lipids in the commercial fish feed industry, but supply is limited. Palm-based oils such as CPO are more cost-effective and abundant compared to fish oil. The physical qualities of floating grower tilapia (*Oreochromis niloticus*) feed pellets containing CPO were comparable to those of the control feed (Mohamed *et al.*, 2023). Another study to evaluate the antioxidant properties of CPO, refined palm oil, RPO, palm kernel oil and soybean oil as well as the influence of these oils on tissue fatty acid deposition, blood lipid profiles and the expression of liver lipid and lipoprotein metabolism genes have also been conducted in laying hens. Dietary supplementation of CPO and RPO decreased serum, liver and jejunal mucosal antioxidant enzyme activities, thus indicating that these oils are associated with lower needs to produce antioxidant enzymes (Izuddin *et al.*, 2023).

New Developments in Palm Oleochemical Applications

The chemical industry, motivated by the advancement in R&D of oleochemicals into oleochemical derivatives, provides a gateway for the production of functional bio-based ingredients. R&D activities on the production of ester compounds are increasing as many new potential applications could be explored. Ester-based compounds find unique synergy when combined with classic chemicals and are used as oil additives, adhesives, sizing binders and surfactants to provide great oxidation stability while enhancing biodegradability. Esters are also utilised in various end-use sectors, including the lubricant, pulp and paper, paint and coatings, construction, cosmetics and personal care industries.

Diethylene glycol dilaurate (DEG-DL) has the potential to be used as a coalescent aid in latex paint formulations. Palm-based DEG-DL may be produced using a solvent-free microwave heating method within 2 hr in the absence of a catalyst, with a significant 24% decrease in the activation energy and a near 100% increase in the pre-exponential factor, thus providing an efficient production process for DEG-DL (Abas *et al.*, 2023). An esterquat, which is a cationic surfactant used in fabric softener formulations, could be produced from palm-based N-methyldiethanolamine di-ester. A new alternative route for the production of palm-based N-methyldiethanolamine di-ester was developed (Aziz *et al.*, 2023a; 2023b).

Glycerol, a by-product from triglyceride splitting and biodiesel processes, could be used as an adjuvant in water-based *d*-phenothrin insecticide formulations (Megat Nabil Mohsin *et al.*, 2023) to prolong suspension time. The glycerol-added formulation was found to be effective against adult *Aedes aegypti*, causing complete knockdown and mortality in adult *A. aegypti* at 25 and 10 m for thermal and cold fogging, respectively.

TRF could be potentially used as a new therapeutic agent for treating skin hyperpigmentation and help to lighten skin tone in skincare product formulations. A *study* to evaluate the effects of palm TRF on ultraviolet-A (UVA)-induced melanogenesis in melanocytes showed a slight decrease in melanin content of about 4%

compared to the irradiated negative control, thus indicating the potential of TRF to effectively protect cells from UVA irradiation (Albakry *et al*., 2023).

CONCLUSION

The Malaysian oil palm industry is gradually recovering from the COVID-19 pandemic, supported by sustained demand and stabilised prices, but faces challenges such as yield stagnation, labour shortages and sustainability concerns. Ongoing upstream R&D initiatives aim to elevate the industry's well-being by focusing on precision agriculture, breeding, pest control and genomics to enhance yields sustainably. Midstream R&D focuses on mill productivity and environmental concerns such as POME, aiming for efficiency and cost reduction. Utilising palm-based biomass is key for a circular economy. Downstream R&D emphasises safe and sustainable palm oil products, prioritising safety and enhancing value. Recognition of many concerted efforts is necessary to ensure the industry's sustainable progression and help direct R&D towards SDGS through efficient management of resources such as human and financial assets. Future R&D endeavours should aim to leverage artificial intelligence for plantation management and milling operations, as well as to identify novel genetic modifications and palm-based ingredients for improved upstream and downstream applications respectively.

ACKNOWLEDGEMENT

The authors appreciate all the contribution and support given by all the divisions in MPOB throughout the process of preparing this manuscript.

REFERENCES

Abas, N A; Yusoff, R; Aziz, H A and Idris, Z (2023). Kinetic study of self-esterified palm-based C12 fatty acid and diethylene glycol using conventional and microwave heating. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0026.

Abdul Ghani, N A; Abdul Nasir, N A; Lambuk, L; Sadikan, M Z; Agarwal, R and Ramli, N (2023). The effect of palm oil-derived tocotrienol-rich fraction in preserving normal retinal vascular diameter in streptozotocin-induced diabetic rats. *Graefes Arch. Clin. Exp. Ophthalmol., 261(6)*: 1587-1596.

Abdullah, N; Zainal, Z; Yaakub, Z; Ahmad Maliki, F; Marjuni, M and Amiruddin, M D (2023). Performance of selfed and intercrossed oil palm Deli Ulu Remis progenies based on selected agronomic traits. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0023.

Abubakar, A; Kasim, S; Ishak, M Y and Uddin, M K (2023). Maximizing oil palm yield: Innovative replanting strategies for sustainable productivity. *J. Environ. Earth Sci., 5(2)*: 61-75.

Ahmad, S N; Mohamad, S A; Arshad, O and Masri, M M M (2023). The influence of flowering beneficial plant, *Turnera subulata* on the insect natural enemies' abundance in relation to oil palm bagworm occurrence in Bagan Datuk, Perak, Malaysia. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0017.

Albakry, N A; Yusof, Y A and Hasan, Z A A (2023). *In vitro* evaluation of melanogenesis inhibition by tocotrienol rich fraction. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0047.

Amit, B; Klok, W R; Meer, P J V D; Nik Sasha Khatrina, K; Yaman, I C and Khoon, K L (2023). The effects of peat swamp forest patches and riparian areas within large scale oil palm plantations on bird species richness. *Trop. Life Sci. Res., 34(2)*: 131-160.

Anuar, M S K; Hashim, A M; Ho, C L; Wong, M-Y; Sundram, S; Saidi, N B and Yusof, M T (2023). Synergism: Biocontrol agents and biostimulants in reducing abiotic and biotic stresses in crop. *World J. Microbiol. Biotechnol., 39(5)*: 123.

Ayob, Z; Kusai, N A; Jantan, N M; Murdi, A A; Law, M C; Khairuddin, N S K and Idris, A S (2023). Methanogenic archaea community in relation to methane production in oil palm planted on tropical peatland. *IOP Conf. Ser.: Earth Environ. Sci., 1167(1)*: 012013.

Aziz, H A; Yusoff, R; Cheng, N G; Idris, Z and Ramli, N A S (2023a). Production of N-methyldiethanolamine di-ester via heterogeneous transesterification of palm methyl ester over modified calcium oxide catalyst by metal oxides. *J. Surfactants Deterg., 26(4)*: 477-490.

Aziz, H A; Yusoff, R; Cheng, N G; Idris, Z and Ramli, N A S (2023b). Production of high content of N-methyldiethanolamine di-ester via heterogeneous transesterification. *Tenside Surfactants Deterg., 60(4)*: 394-408.

Baharum, S N; Ahmad, M F; Ajeng, A A and Abdullah, R (2023). Metabolites profiling of *Ganoderma*-infected oil palms rachis grown on tropical soils reveals choline phosphate and 2-oxoglutaramate as potential biomarkers in the disease detection. *Physiol. Mol. Plant Pathol., 125*: 102001.

Bakeri, S A; Moslim, R; Ghani, I A; Masri, M M M and Jalinas, J (2023). Population dynamics of adult *Oryctes rhinoceros* and its developmental stages with *Oryctes* Nudivirus infection in a zero burning replanting area. *Int. J. Trop. Insect Sci., 43(2)*: 591-600.

Bicknell, J E; O'Hanley, J R; Armsworth, P R; Slade, E M; Deere, N J; Mitchell, S L; Hemprich-Bennett, D; Kemp, V; Rossiter, S J; Lewis, O T *et al.* (2023). Enhancing the ecological value of oil palm agriculture through set-asides. *Nat. Sustain., 6(5)*: 513-525.

Bukhari, N A (2023). Prospects and state-of-the-art in production of bio-based succinic acid from oil palm trunk. *J. Oil Palm Res., 35(4)*: 555-581.

China Dialogue (2023). How can the palm oil industry reach net zero? https://chinadialogue.net/en/climate/how-can-palm-oil-reach-net-zero/, accessed on 18 April 2024.

Darlis, D; Jalloh, M B; Chin, C F S; Basri, N K M; Besar, N A; Ahmad, K and Rakib, M R M (2023). Exploring the potential of Bornean polypore fungi as biological control agents against pathogenic *Ganoderma boninense* causing basal stem rot in oil palm. *Sci. Rep., 13(1)*: 10316.

Denan, N; Norhisham, A R; Sanusi, R; Stone, J and Azhar, B (2023). Stand-level habitat characteristics and edge habitats drive biological pest control services in the understory of oil palm plantations. *Biol. Control, 183*: 105261.

Diana, S R and Farida, F (2023). Applying bag of words approach to determine remote sensing technology acceptance among smallholder plantations. *Arab Gulf J. Sci. Res.* DOI: 10.1108/agjsr-02-2023-0056.

Dzulkafli, S B; Othman, A; Lau, B Y C; Nurazah, Z; Nagappan, J; Ramli, U S and Karsani, S A (2023). Understanding the effects of carbon and nitrogen starvation on the comparative secretomes of *Ganoderma boninense* and *Ganoderma tornatum*. *Physiol. Mol. Plant Pathol., 127*: 102084.

Faridah, M R; Yusoff, M M; Rozzamri, A; Ibadullah, W Z W; Hairi, A N A; Daud, N H A; Huda, N and Ismail-Fitry, M R (2023). Effect of palm-based shortenings of various melting ranges as animal fat replacers on the physicochemical properties and emulsion stability of chicken meat emulsion. *Foods, 12(3)*: 597.

Fizree, M D P M A A; Masani, M Y A; Shaharuddin, N A; Ho, C L; Manaf, M A A and Parveez, G K A (2023). Efficient PEG-mediated transformation of oil palm mesophyll protoplasts and its application in functional analysis of oil palm promoters. *S. Afr. J. Bot., 155*: 187-195.

Harahap, I A; Sabrina, T and Mukhlis, M (2023). Carbon dioxide emissions at the peatland in oil palm plantations: Groundwater, subsidence, and climate. *Proc. 3rd Prog. Soc. Sci. Humanit. Educ. Res. Symp.* Universitas Negeri Padang. p. 316-323.

Hassim, N A M; Kanagaratnam, S; Saw, M H; Ismail, N H; Hamid, R A; Miskandar, M H and Sofian-Seng, N S (2023). Characteristics of sunflower wax, carnauba wax and beeswax in palm superolein blended oil. *J. Oil Palm Res., 35(4): 694-712*.

Ismail, A and Kamil, N N (2023). Report on labour situation in the Malaysian oil palm plantation sector (Fourth quarter 2022). *MPOB Report EID (15) 2023*.

Ismail, M; Juraimi, A S; Idris, A S; Rusli, M H; Omar, R Z R; Tohiran, K A and Husri, M N (2023a). Effects of culture medium and light durations on the fungal growth of *Bipolaris sorokiniana*. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0010.

Ismail, N H; Hamid, R A; Hassim, N A M and Kanagaratnam, S (2023b). Palm-based mozzarella cheese analogue. *MPOB Information Series No. 851*.

Izuddin, W I; Loh, T C; Nayan, N; Akit, H; Foo, H L and Noor, A M (2023). Antioxidant enzyme system modulation by dietary palm oils, palm kernel oil and soybean oil in laying hens. *Animals (Basel), 13(14)*: 2245.

Izzuddin, M A; Hamzah, A; Nisfariza, M N; Idris, A S; Nor Aizam, A; Sharul Aikal, B M; Nordiana, A A; Mohd Najib, A and Mohd Shukri, I (2023). Denoising of hyperspectral signal from drone for *Ganoderma* disease detection in oil palm. *Int. J. Geoinformatics, 19(5)*: 55-60.

Jinadasa, B K K K; Van Bockstaele, F; Cvejic, J H and Simal-Gandara, J (2022). Chapter 11 - Current trends and next generation of future edible oils. *Future Foods: Global Trends, Opportunities, and Sustainability Challenges* (Bhat, R ed.). Academic Press, Cambridge, Massachusetts, United States. p. 203-231.

Khoo, Y W and Chong, K P (2023). *Ganoderma boninense*: General characteristics of pathogenicity and methods of control. *Front. Plant Sci., 14*: 1156869.

Khor, J F; Ling, L; Yusop, Z; Chin, R J; Lai, S H; Kwan, B H and Ng, D W K (2023). Impact comparison of *El Nino* and ageing crops on Malaysian oil palm yield. *Plants (Basel), 12(424)*: 19.

Li, K; Grass, I; Zemp, D C; Lorenz, H; Sachsenmaier, L; Nurdiansyah, F; Holscher, D; Kreft, H and Tscharntke, T (2023). Tree identity and canopy openness mediate oil palm biodiversity enrichment effects on insect herbivory and pollination. *Ecol. Appl., 33(5)*: e2862.

Lim, C H; Loh, Y W; Foo, D C; Ng, W P and Lam, H L (2021). Circular economy and industry 4.0 technology integration framework for the oil palm industry. *Chem. Eng. Trans., 88*: 1267-1272.

Lim, F H; Rasid, O A; Idris, A S; As'wad, A W M; Vadamalai, G; Parveez, G K A and Wong, M-Y (2023). Induced expression of *Ganoderma boninense* Lanosterol 14α-Demethylase (ERG11) during interaction with oil palm. *Mol. Biol. Rep., 50(3)*: 2367-2379.

Lo, M L; Thanh, T A V; Midot, F; Lau, S Y L; Wong, W C; Tung, H J; Jee, M S; Chin, M Y and Melling, L (2023). Comparison of *Ganoderma boninense* isolate's aggressiveness using infected oil palm seedlings. *J. Microbiol., 61(4)*: 449-459.

Loh, S K; Nasrin, A B; Sukiran, M A; Bukhari, N A; Muzzammil, N; Stasha Eleanor, R A and Astimar, A A (2020). The future of biogas in the Malaysian palm oil industry: Why need methane capture? *Palm Oil Developments, 72*: 1-7.

Mahiran, S N S N; Ravi, N; Mahboob, A and Kadir, N H A (2023). Selective cytotoxicity effects of R-glycidol and S-glycidol on Vero and HCT 116 cells in evaluating the incidence of glycidyl esters in edible oils and fats. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0049.

Maidin, M S T; Hashim, A M; Kamarudin, N; Ahmad, S N; Masri, M M M; Rahim, R A and Jamian, S (2023). Identification of the oil palm bagworm, *Mahasena corbetti* Tams (Lepidoptera: Psychidae) via molecular techniques and its biocontrol assay using *Bacillus thuringiensis*. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0036.

Masure, A; Martin, P; Lacan, X and Rafflegeau, S (2023). Promoting oil palm-based agroforestry systems: An asset for the sustainability of the sector. *Cah. Agric., 32*: 16.

McCalmont, J; Kho, L K; Teh, Y A; Chocholek, M; Rumpang, E; Rowland, L; Basri, M H A and Hill, T (2023). Oil palm (*Elaeis guineensis*) plantation on tropical peatland in South East Asia: Photosynthetic response to soil drainage level for mitigation of soil carbon emissions. *Sci. Total Environ., 858(1)*: 159356.

Megat Nabil Mohsin, S; Ahmad, N and Yusof, Y A (2023). Comparative efficacy trials with alcohol added *d*-phenothrin formulations against *Aedes aegypti* under open-field condition. *Pest Manag. Sci., 79(10)*: 4094-4099.

Mohamed, W N W; Noh, A M; Ibrahim, N A; Mookiah, S; Fuat, M A and Mohammad, M (2023). Physical quality of floating grower tilapia feed pellets supplemented with different levels of crude palm oil. *Livest. Res. Rural Dev., 35(1)*: 10.

Mohan, D; Namasivayam, P; Saidi, N B and Ho, C L (2022). Temporal expression of defense-related genes in *Ganoderma*-infected oil palm roots. *Trees, 36(3)*: 1029-1038.

Mohd Suib, N A B; Salleh, N H M; Shukor, M S; Chamhuri, N; Shahimi, S; Salleh, K M and Hashim, K (2023). The influence of good agricultural practice (GAP) on the productivity and well-being of Malaysian sustainable palm oil (MSPO)-certified independent smallholders in Malaysia. *Agriculture, 13(5)*: 990.

MPOB (2024). *Malaysian Oil Palm Statistics 2023.* 43rd edition. MPOB. Bangi.

Mustafa, I F; Hussein, M Z; Idris, A S; Ramli, N R; Mustafa, M and Fakurazi, S (2023). *Pseudomonas aeruginosa* encapsulated with calcium carbonate microshells for potential biocontrol of the *Ganoderma boninense*. *Korean J. Chem. Eng., 40(4)*: 854-862.

Naidu, Y; Siddiqui, Y; Sundram, S; Rusli, M H and Idris, A S (2023). Profiling of oxidative enzymes and structural characterization of biologically pretreated oil palm wood chips. *Eur. J. Wood Wood Prod., 81(5)*: 1277-1289.

Napiah, N R A M A; Kamarudin, N; Bakeri, S A; Zainuddin, N; Keni, M F and Masri, M M M (2023). Impact of environmental factors on the larval population of bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae) in oil palm smallholdings. *Serangga, 28(2)*: 149-161.

Nasrin, A B; Raman, A A A; Sukiran, M A; Bukhari, N A; Buthiyappan, A; Subramaniam, V; Aziz, A A and Loh, S K (2023). Renewable energy and greenhouse gases emission reduction potential of biogas from palm oil mill effluent. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0032.

Ng, M H; Amri, I N; Rahmat, C M C; Nu'man, A H; Hasliyanti, A and Rohaya, M H (2023). Potential of nuclear magnetic resonance for the determination of organochlorine in edible oils. *J. Food Compos. Anal., 122*: 105492.

Ng, M H and Nu'man, A H (2023). Consolidation of deep eutectic solvents with microwave for the extraction of ferulic acid from the fruitlets of oil palm. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0022.

Nik Azmi, N N A; Tan, T C; Ang, M Y and Leong, Y H (2023). Occurrence and risk assessment of 3-monochloropropanediols esters (3-MCPDE), 2-monochloropropanediol esters (2-MCPDE), and glycidyl esters (GE) in commercial infant formula samples from Malaysia. *Food Addit. Contam. Part A: Chem. Anal. Control Expo. Risk. Assess., 40(2)*: 212-221.

Oil World (2024). *Oil World Weekly.* No. 4-6, Vol. 67, Jan-Feb 2024. Germany, ISTA Mielke GmbH.

Ooi, L C L; Kamil, N N; Mohd Salleh, K; Leslie Low, E T; Ong Abdullah, M; Lakey, N; Ordway, J M; Garner, P A; Nookiah, R; Sambanthamurthi, R; Abd Manaf, M A; Ismail, A and Singh, R (2023). Improving oil palm sustainability with molecular-precision agriculture: Yield impact of SHELL DNA testing in the Malaysian oil palm supply chain. *Sci. Hortic., 321*: 112305.

Paterson, R R M (2023). Future climate effects on yield and mortality of conventional versus modified oil palm in SE Asia. *Plants (Basel), 12(12)*: 2236.

Periasamy, G; Yun, W M; Vadamalai, G; Ling, H C; Naidu, Y R and Sundram, S (2023). Ligninolytic enzymes profiling in association with the aggressiveness of *Ganoderma boninense* isolates. *Malays. J. Microbiol., 19(1)*: 11-21.

Phang, S C W; Ahmad, B; Abdul Kadir, K and Uma Devi, M P (2023). Effects of tocotrienol-rich fraction supplementation in patients with type 2 diabetes: A systematic review and meta-analysis of randomized controlled trials. *Adv. Nutr., 14(5)*: 1159-1169.

Ramli, N A S; Roslan, N A; Abdullah, F; Bilal, B; Ghazali, R; Abd Razak, R A and Ahmad Tarmizi, A H (2023a). Determination of process contaminants 2- and 3-MCPD esters and glycidyl esters in palm-based glycerol by indirect analysis using GC-MS. *Food Addit. Contam. Part A: Chem. Anal. Control Expo. Risk. Assess., 40(10)*: 1-15.

Ramli, N A S; Roslan, N A; Abdullah, F; Ghazali, R; Razak, R A A; Tarmizi, A H A and Bilal, B (2023b). Analytical method for the determination of 2- and 3-monochloropropane-diol esters and glycidyl ester in palm-based fatty acids by GC-MS. *Food Control, 151*: 109824.

Sadikan, M Z; Abdul Nasir, N A; Bakar, N S; Iezhitsa, I and Agarwal, R (2023). Tocotrienol-rich fraction reduces retinal inflammation and angiogenesis in rats with streptozotocin-induced diabetes. *BMC Complement. Med. Ther., 23(1)*: 179.

Santiago, K A A; Wong, W C; Goh, Y K; Tey, S H and Ting, A S Y (2023). Metabolomics approach in identifying biomarkers from pathogenic *Ganoderma boninense* involved in early interactions with oil palm host. *Physiol. Mol. Plant Pathol., 125*: 101980.

Sapian, N A S; Roslan, M A M; Hashim, A M; Manaf, Y N A; Desa, M N M; Halim, M; Sani, M S A; Yusof, M T; Dek, M S P and Wasoh, H (2023). N-alkane profiles of lard and vegetable oils, and their chemometrics differentiation. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0038.

Saw, M H; Lim, W H; Yeoh, C B and Tan, C P (2023). Effect of storage temperature and duration on rheological and thermal characteristics of superolein oleogels. *J. Oil Palm Res., 35(2)*: 256-267.

Shaikh, S A and Muthuraman, A (2023). Tocotrienol-rich fraction ameliorates the aluminium chloride-induced neurovascular dysfunction-associated vascular dementia in rats. *Pharmaceuticals (Basel), 16(6)*: 828.

Shokrollahi, N; Ho, C L; Zainudin, N A I M; Wahab, M A B A and Wong, M Y (2023). Plant defense inducers and antioxidant metabolites produced during oil palm-*Ganoderma boninense* interaction *in vitro*. *Chem. Afr., 6*: 499-511.

Siagian, U W R; Wenten, I G and Khoiruddin, K (2024). Circular economy approaches in the palm oil industry: Enhancing profitability through waste reduction and product diversification. *J. Eng. Technol. Sci., 56(1)*: 25-49.

Sibhatu, K T (2023). Oil palm boom: Its socioeconomic use and abuse. *Front. Sustain. Food Syst., 7*: 1083022.

Singh, R; Kamil, N N; Ooi, L C L; Low, E T L; Abdullah, M O; Sambanthamurthi, R; Lakey, N; Abd Manaf, M A and Ismail, A (2022). SHELL genetic testing: A key enabler of yield improvement and sustainable palm oil production. *The Planter, 98(1159)*: 713-727.

Siti-Dina, R P; Er, A C and Cheah, W Y (2023). Social issues and challenges among oil palm smallholder farmers in Malaysia: Systematic literature review. *Sustainability, 15(4)*: 3123.

Syarif, M N Y; Asib, N; Ahmad, S N; Bakeri, S A; Masri, M M M and Omar, D (2023). Identification of *Cordyceps javanica* and its effectiveness in controlling bagworm, *Pteroma pendula* Joannis (Lepidoptera: Psychidae). *Serangga, 28(2)*: 14-27.

Tahir, N I; Ishak, A N; Sin, T S; Othman, A and Ramli, U S (2023). Chemical profiling of palm oil and other selected plant oils by proton nuclear magnetic resonance combined with chemometrics. *J. Oil Palm Res*., *35(4)*: 738-746.

Tchounke, B; Sanchez, L; Bell, J M and Cros, D (2023). Mate selection: A useful approach to maximize genetic gain and control inbreeding in genomic and conventional oil palm (*Elaeis guineensis* Jacq.) hybrid breeding. *PLoS Comput. Biol., 19(9)*: e1010290.

Teh, S S and Lau, H L N (2023). Phytonutrient content and oil quality of selected edible oils upon twelve months storage. *J. Am. Oil Chem. Soc., 100(8)*: 651-661.

Teh, S S; Lau, H L N and Wafti, N S B A (2023). Storage stability and degradation kinetics of phytonutrients of red palm-pressed mesocarp olein. *J. Oleo. Sci., 72(5)*: 511-520.

Tohiran, K A; Nobilly, F; Zulkifli, R; Yahya, M S; Norhisham, A R; Rasyidi, M Z and Azhar, B (2023). Multi-species rotational grazing of small ruminants regenerates undergrowth vegetation while controlling weeds in the oil palm silvopastoral system. *Agric. Syst., 210*: 103720.

Wahab, N A; Ramli, Z; Manaf, M A A and Parveez, G K A (2023). Oil palm MSP2 promoter isolation, *in silico* analysis and functional characterisation. *J. Oil Palm Res., 35(3)*: 491-503.

Zainuddin, N; Maidin, M S T; Kamarudin, N; Napiah, N R A M A; Keni, M F and Masri, M M M (2023). *De novo* transcriptome analysis of bagworm *Metisa plana* from highly infested oil palm estate in Perak revealed detoxification genes and potential insecticide targets. *J. Asia Pac. Entomol., 26(1)*: 102039.

Zakaria, L (2023). Basal stem rot of oil palm: The pathogen, disease incidence, and control methods. *Plant Dis., 107(3)*: 603-615.

Zulkefli, M H H; Ismail, S J I; Adam, N A; Jalinas, J and Masri, M M M (2023). Nutritional composition of anthesising male inflorescence of oil palm *Elaeis guineensis* essential for development of *Elaeidobius kamerunicu*s Faust: First report. *J. Oil Palm Res*. DOI: 10.21894/jopr.2023.0027.