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Valorization of palm-pressed mesocarp fiber (PPMF): a rich source of insoluble dietary fiber with functional and health-promoting properties

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SUMMARY: This study evaluates palm-pressed mesocarp fiber (PPMF), a lignocellulosic by-product of palm oil extraction, as a functional ingredient with potential health benefits relevant to the oil and fat industry. Dietary fiber content, along with physicochemical and functional properties, were comprehensively characterized. A proximate analysis revealed a high insoluble dietary fiber content (86.13 %), surpassing that of the oil palm trunk (73.93 %) and many commonly consumed fiber-rich foods (56-74 %). The functional properties of PPMF such as water retention capacity (12.87 g/g), water swelling capacity (3.31 mL/g), and oil holding capacity (3.29 g/g) were within ranges typical for dietary fibers, indicating suitability for incorporation in food formulations. Notably, PPMF exhibited strong α-amylase inhibitory activity (65.79 %), suggesting a role in managing postprandial glucose levels. These findings highlight PPMF as a sustainable, high-fiber by-product with promising applications in functional food development and value addition within the lipid-processing industry, contributing to improved nutritional profiles and waste valorization.

KEY-WORDS: *Palm-pressed mesocarp fiber; Oil palm trunk; Glucose level; Gut microbiota; α-amylase inhibitory activity; Diabetes.*

RESUMEN: ***Valorización de la fibra de mesocarpio de palma prensada (PPMF): una fuente rica en fibra dietética insoluble con propiedades funcionales y promotoras de la salud.*** Este estudio evalúa la fibra de mesocarpio prensada de palma (PPMF), un subproducto lignocelulósico de la extracción de aceite de palma, como ingrediente funcional con potenciales beneficios para la salud y relevante para la industria de aceites y grasas. Se caracterizó exhaustivamente el contenido de fibra dietética, junto con las propiedades fisicoquímicas y funcionales. El análisis proximal reveló un alto contenido de fibra dietética insoluble (86,13 %), superando al del tronco de palma aceitera (73,93 %) y a muchos alimentos ricos en fibra de consumo común (56-74 %). Las propiedades funcionales de la PPMF, como la capacidad de retención de agua (12,87 g/g), la capacidad de hinchamiento en agua (3,31 mL/g) y la capacidad de retención de aceite (3,29 g/g), se encontraron dentro de los rangos típicos para las fibras dietéticas, lo que indica su idoneidad para su incorporación en formulaciones alimentarias. Cabe destacar que la PPMF exhibió una fuerte actividad inhibidora de la α-amilasa (65,79 %), lo que sugiere un papel en el manejo de los niveles de glucosa posprandial. Estos resultados destacan al PPMF como un subproducto sostenible y rico en fibra con aplicaciones prometedoras en el desarrollo de alimentos funcionales y la adición de valor para la industria de procesamiento de lípidos, contribuyendo a la mejora de los perfiles nutricionales y la valorización de residuos.

PALABRAS CLAVE: *Actividad inhibidora de la α-amilasa; Diabetes; Fibra de mesocarpio prensada de palma; Microbiota intestinal; Nivel de glucosa; Tronco de palma aceitera.*

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1. INTRODUCTION

Malaysia cultivates approximately 5.61 million hectares of oil palm, a crop of significant economic importance that yields about 10 % palm oil and 90 % lignocellulosic oil palm biomass (OPB) as by-products (Parveez *et al.*, 2025). While palm oil serves a versatile role across food and non-food industries, OPB offers substantial potential for value-added applications but remains underutilized. In 2023, OPB production (dry weight basis) comprised mill residues: palm-pressed mesocarp fibre (PPMF, 7.23 million tonnes), empty fruit bunches (EFB, 6.87 million tonnes), palm kernel shell (PKS, 4.17 million tonnes); and plantation residues including oil palm trunk (OPT, 9.82 million tonnes) and oil palm frond (OPF, 63.41 million tonnes).

PPMF is the fibrous middle layer of the oil palm fruit mesocarp. Currently, approximately 92.4 % of palm oil mills utilize PPMF as sustainable fuel for captive boilers, with the remainder sold commercially (Malaysian Palm Oil Board; Department of Statistics Malaysia). Beyond its role as biofuel, PPMF's lignocellulosic composition positions it as a promising raw material for bio-composite production through the reinforcement of polymer matrices, yielding thermoplastic materials (Nordin *et al.*, 2013). Additionally, PPMF can serve as a feedstock for green fuel generation (Zamri *et al.*, 2022) or as a source for extracting red palm-pressed mesocarp oil (Lau, *et al.*, 2006).

Despite these applications, the nutritional and functional potential of PPMF remains underexplored. Comprising primarily hemicellulose, cellulose, and lignin, PPMF is rich in insoluble dietary fiber (IDF) (Yang *et al.*, 2021), which is known to enhance gut immunity, intestinal integrity, mucosal cell growth, and probiotic adhesion, collectively promoting gastrointestinal health. IDF also facilitates increased bioavailability of plant polyphenols, amplifying their health benefits (Baky *et al.*, 2024). However, in humans, phenolic compounds bound to IDF are not readily absorbed in the small intestine. They pass into the colon instead, where they may undergo fermentation by gut microbiota, potentially releasing bioactive metabolites (Zheng *et al.*, 2024). Animal studies have demonstrated that IDF-rich foods, such as enoki mushrooms, carrots, and oats, improve glucose tolerance and attenuate lipid increases following dietary fat intake (Yang *et al.*, 2021).

Despite recommended daily dietary fiber intakes of 28-34 g for adults (USDA), actual consumption remains critically low (Barber *et al.*, 2020; Lee and Wan Muda, 2019), contributing to elevated risks of cardiovascular disease, metabolic dysfunction, neurological disorders, autoimmune conditions, and cancer (Ioniță-Mîndrican *et al.*, 2022). In Malaysia, average daily fiber intake is reported at only 2.8 g for men and 3.1 g for women, far below guidelines (Lee and Wan Muda, 2019). Moreover, popular exclusion diets such as paleo, keto, and gluten-free often eliminate fiber-rich grains and legumes, potentially compromising cholesterol and blood glucose regulation (McKeown *et al.*, 2022).

In light of these concerns, this study characterizes PPMF as an alternative dietary fiber source, assessing its proximate composition, physicochemical properties including dietary fiber content, water retention capacity (WRC), water swelling capacity (WSC), oil holding capacity (OHC) and functional properties including glucose adsorption capacity (GAC) and α-amylase inhibitory activity. For comparative purposes, OPT, another nutrient-rich plantation residue (Dirkes *et al.*, 2021), was included in the analyses.

2. MATERIALS AND METHODS

2.1. Materials

Sterilized palm fruits and OPT were collected from a local palm oil mill (Malaysia). Palm fruits were peeled, washed and dried in an oven, followed by grinding to break up the fibers to obtain PPMF. OPT was sawn into approximately 8-cm square segments using sawmill machinery, followed by grinding into powder form. Both PPMF and OPT were successively extracted with *n*-hexane to remove extractives and obtain extractive-free samples for subsequent analyses. The extraction was conducted using a solid-to-liquid ratio of 1:10 (w/v), with three consecutive extraction cycles using Soxhlet apparatus at 60 °C for 4 hours. After extraction, the samples were filtered, rinsed with fresh *n*-hexane, and air-dried under a fume hood, followed by oven-drying at 40 °C until a constant weight was achieved.

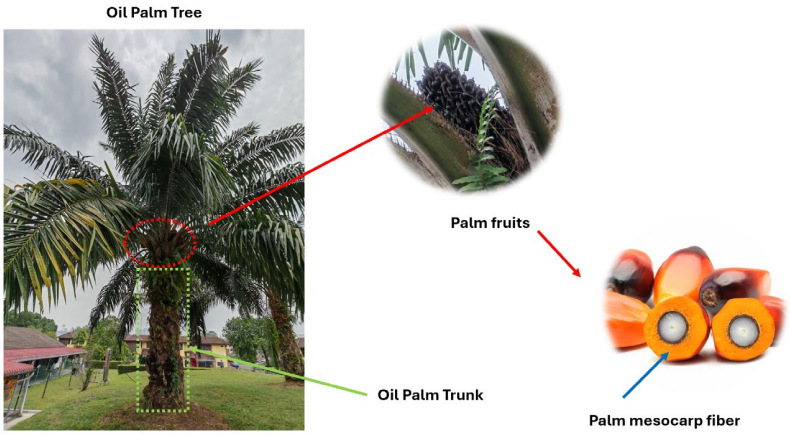

FIGURE 1. Source of palm-pressed mesocarp fiber (PPMF) and oil palm trunk (OPT) from the oil palm

n-hexane was purchased from Merck KGaA (Darmstadt, Germany), other chemicals were purchased from R&M Sdn. Bhd. (Selangor, Malaysia). A total dietary fibre (TDF) assay kit was purchased from Megazyme (Bray, Ireland).

2.2. Proximate analysis

2.2.1. Determination of oil

The oil content in the samples was determined as mentioned in Session 2.1 - Materials and calculated as follows:

$$\text{Oil (\%)} = W_o/W_s \times 100 \quad (1)$$

where W_o = weight of oil (g) and W_s = weight of sample before extraction (g)

2.2.2. Determination of moisture

The moisture content in the samples was measured following the AOAC Official Method 925.09. In brief, the drying, cooling and weighing of the samples were carried out repeatedly until a constant weight was obtained. The moisture content in a sample was calculated as follows:

$$\text{Moisture (\%)} = (W_1-W_2)/W_1 \times 100 \quad (2)$$

where W_1 = weight of sample before drying (g), and W_2 = weight of sample after drying (g)

2.2.3. Determination of protein

Protein content in the samples was measured according to the AOAC Official Method 955.04, which quantifies nitrogen-containing compounds through the Kjeldahl method. The analysis was conducted using a KjelROC Analyzer (OPSIS, Furulund, Sweden), an automated system designed for digestion, distillation, and titration steps involved in Kjeldahl nitrogen determination. Protein percentage was calculated by the analyzer's software by applying a nitrogen-to-protein conversion factor of 6.25.

2.2.4. Determination of ash

The ash content in the samples was determined according to the AOAC Official Method 942.05 using a Thermogravimetric Analyzer TGA-701 (LECO, USA). In brief, the sample was ignited at 600 °C for 2 hours. The ash content in the sample was calculated as follows:

$$\text{Ash (\%)} = W_a/W_b \times 100 \quad (3)$$

where W_a = weight of ash (g), and W_b = weight of sample before (g)

2.2.5. Determination of carbohydrate

The carbohydrate content in the samples was determined with the following calculation:

$$\text{Carbohydrate (\%)} = 100 - \text{moisture content} - \text{protein content} - \text{oil content} - \text{ash content} \quad (4)$$

2.3. Physicochemical and functional properties of dietary fibers

2.3.1. Dietary fiber content

Soluble dietary fiber (SDF) and IDF contents were determined following the AOAC Official Method 991.43, an enzymatic-gravimetric procedure. This method involves sequential enzymatic digestion of the sample using heat-stable α-amylase, protease, and amyloglucosidase to remove starch and protein components. After digestion, the residue was filtered where IDF was washed, dried, and weighed, while SDF was precipitated from the filtrate by adding 78 % ethanol, filtered, dried, and weighed. TDF is the total of IDF and SDF. All fiber fractions were corrected for protein and ash content. Fiber contents are expressed as weight percent (wt. %), indicating the amount of each fiber component per 100 grams of sample by weight.

2.3.2. Water retention capacity (WRC)

The WRC of extractive-free samples was assessed using the method described by Robertson and coworkers (2000). A 0.2 g sample was soaked in 6 mL of distilled water at room temperature for 18 hours, then centrifuged at 6700 rpm for 15 minutes. The weight of the resulting residue was measured before and after drying, with the fresh and dry residues being recorded at 105 °C until a constant weight was reached. WRC was then calculated using the following equation:

$$\text{WRC (g/g) of sample} = (m_f - m_d)/m_d \quad (5)$$

where m_f is the weight of the fresh residue (g) and m_d is the weight of the dry residue (g).

2.3.3. Water swelling capacity (WSC)

The WSC of the extractive-free samples was measured using the method described by Sowbhagya and coworkers (2007), with some modifications. The sample (0.2g) was hydrated in 15 mL distilled water in a graduated test tube at room temperature for 18 hours. The bed volume was recorded, and WSC was calculated using the following equation:

$$\text{WSC (mL/g) of sample} = (V_1 - V_0)/W_0 \quad (6)$$

where V_1 is the volume of the hydrated sample (mL), V_0 is the volume of sample prior to hydration (mL), and W_0 is the weight of sample prior to hydration (g).

2.3.4. Oil holding capacity (OHC)

The OHC of extractive-free samples was determined according to the method described by Zhang and coworkers (2011). A sample (1g) was mixed with 10 mL soybean oil in a centrifuge tube and allowed to stand at room temperature for 1 h. The mixture was then centrifuged at 3700 rpm for 10 min. The pellet was recovered by filtrating through a nylon cloth after decanting the supernatant. The OHC of PPMF was calculated as follows:

$$\text{OHC (g/g) of sample} = (M_p - M_d)/M_d \quad (7)$$

where M_p is the pellet weight (g) and M_d is the dry weight of the sample (g).

2.3.5. Glucose adsorption capacity (GAC)

The GAC of extractive-free samples was determined according to the method described by Daou and Zhang (2014) with some modifications. A sample (0.25 g) was mixed with a 25-mL 100 mmol/L glucose solution,

followed by incubation at 37 °C for 6 hours. The sample was then centrifuged at 6000 rpm for 15 min. The supernatant was filtered, and the glucose content in the supernatant was measured using High-Performance Liquid Chromatography (HPLC) coupled with a Refractometry (RI) detector. The chromatographic conditions were as follows: Agilent Hi-Plex H column (300 × 7.7 mm, 8 µm particle size), 0.008 M sulfuric acid as the mobile phase, flow rate of 0.6 mL/min, column temperature maintained at 60 °C and injection volume of 10 µL. An external standard calibration curve was employed, using glucose standards to quantify the glucose content in the samples. The GAC of the sample was calculated as follows:

$$\text{GAC (mmol/g) of sample} = (C_1\text{-}C_2) \times V_i/M_d \quad (8)$$

where C_1 is the original glucose content in the solution (mmol), C_2 is the glucose content in the supernatant (mmol/L), Vi is the supernatant volume (mL) and M_d is the dry weight of the sample (g).

2.3.6. *α–amylase inhibitory activity*

α–amylase inhibitory activity of extractive-free samples was determined according to the method described by Ma and Mu (2016) with some modifications. Starch (16 g) was mixed with a 400-mL 0.05 mol/L phosphate buffer (pH 6.5) at 65 °C for 30 min in a beaker, then adjusted to 4 % w/v starch solution. Meanwhile, 0.4 % α-amylase and 1 % sample were added into the prepared starch and transferred into a visking tube. The tube was then dialyzed against 200 mL distilled water in a shaking water bath under the following conditions: pH 7.0, 37 °C and 60 min. Dialysate glucose content was determined after 60 min using a UV spectrometer (SPECTROstar Nano, Germany) at 540 nm. A control test was also carried out without dietary fiber (DF).

$$\alpha - \text{amylase inhibitory activity (\%) of sample} = (A_c - A_s) *100/ A_c \quad (9)$$

where A_c is the control absorbance, A_s is the sample absorbance.

2.4. Statistical Analysis

All data are presented as mean ± standard deviation. Statistical analyses were conducted using GraphPad Prism 9. Multiple independent (unpaired) t-tests were performed to compare groups, and a p-value of less than 0.05 was considered statistically significant. All analyses were performed in triplicate.

3. RESULTS AND DISCUSSION

Proximate analysis of PPMF and OPT (Table 1) revealed that protein, oil, and carbohydrate contents ranged from 0.47 to 2.25 g/100 g, 4.22 to 7.61 g/100 g, and 77.56 to 83.34 g/100 g, respectively. PPMF exhibited significantly lower protein and oil content than OPT, reflecting compositional differences among OPB sources and indicating potential variability in their functional and nutritional applications.

TABLE 1. Proximate analysis of palm-pressed mesocarp fiber and oil palm trunk

	Content (g/100g)	
	PPMF	**OPT**
Moisture content	9.45 ± 0.09[a]	10.65 ± 0.09[b]
Protein content	2.25 ± 0.47[b]	0.47 ± 0.00[a]
Fat content	7.61 ± 0.61[b]	4.22 ± 1.30[a]
Carbohydrate content (calculated)	77.56	83.34
Ash	3.13 ± 0.22	1.32 ± 0.83
Protein (wt. %)	2.57	0.53
Fat (wt. %)	8.71	4.79
Carbohydrate (wt. %)	88.72	94.67

Note: Each data represents the mean ± SD of three independent experiments where means with different letters in the same row indicate significant differences ($p < 0.05$) based on multiple independent (unpaired) t-tests. PPMF: palm-pressed mesocarp fiber; OPT: oil palm trunk.

It is important to note that carbohydrate content was calculated by difference (total minus protein, fat, moisture, and ash), a standard proximate analysis method that can incorporate non-carbohydrate components such as lignin, especially in lignocellulosic materials like PPMF and OPT. Lignin, while not a carbohydrate, is included within DF due to its indigestibility and functional properties. Therefore, a direct enzymatic-gravimetric method (Megazyme kit) to quantify DF, including soluble and insoluble fractions, providing a more precise measure of DF components distinct from total carbohydrates was used.

The analysis of DF profiles (Table 2) demonstrated exceptionally high TDF content in both PPMF and OPT, ranging from 80.54 to 89.41 % (wt.) and IDF from 73.93 to 86.13 % (wt.). These values surpass the typical IDF levels found in common food sources such as grains, legumes, vegetables, fruits, nuts, and seeds, which generally range between 0.3 to 22.3 g/100 g edible portion depending on the source (Dhingra *et al.*, 2012). Notably, IDF comprises 56–74 % of TDF in many staple foods (Wang *et al.*, 2014), whereas PPMF and OPT provide an even higher proportion, highlighting their potential as valuable functional ingredients with health benefits associated with high IDF intake.

TABLE 2. Dietary fiber content of palm-pressed mesocarp fiber and oil palm trunk

wt. %	**PPMF**	**OPT**
Insoluble dietary fiber (IDF)	86.13 ± 0.15^{b}	73.93 ± 1.55^{a}
Soluble dietary fiber (SDF)	3.28 ± 0.25^{a}	6.64 ± 0.88^{b}
Total dietary fiber (TDF) (calculated)	89.41	80.54

Note: Each data represents the mean ± SD of three independent experiments where means with different letters in the same row indicate significant differences ($p < 0.05$) based on multiple independent (unpaired) t-tests. PPMF: palm-pressed mesocarp fiber; OPT: oil palm trunk.

WRC reflects the ability of fiber to retain water against external forces, a key factor in food formulation and processing. Both PPMF and OPT displayed medium to high WRC values (Table 3), consistent with the capacity needed for effective incorporation into food systems to improve texture and moisture retention. These findings align with reported WRC ranges for dietary fibers such as sugar beet fiber (26.5–35.4 g/g), carrot fiber (18.6 g/g), and wheat bran (2.8–3.6 g/g) (Mehta *et al.*, 2013). High WRC fibers are desirable as functional ingredients in meat products and emulsions, enhancing yield and stability during processing.

TABLE 3. Dietary fiber characterization of palm-pressed mesocarp fiber and oil palm trunk

	PPMF	**OPT**
Water retention capacity (WRC), g/g	12.87 ± 0.01	12.84 ± 3.82
Water swelling capacity (WSC), mL/g	3.31 ± 0.57	2.31 ± 0.58
Oil holding capacity (OHC), g/g	3.29 ± 0.88	3.06 ± 0.09

Note: Each data represents the mean ± SD of three independent experiments. PPMF: palm-pressed mesocarp fiber; OPT: oil palm trunk.

WSC is an indicative of fiber swelling in aqueous systems without external stress, is critical for both technological functionality and physiological effects (Nevara, *et al.*, 2021). PPMF and OPT exhibited similar WSC values (2.31–3.31 mL/g), consistent with values reported for dietary fibers from various sources (He *et al.*, 2022). WSC is influenced by the chemical structure of dietary fibers, which governs their hydration and interaction with food matrices.

OHC measures the ability of fibers to absorb and retain oils, a property correlated with their density, surface characteristics, and hydrophobicity. Both PPMF and OPT demonstrated OHC within typical dietary fiber ranges (0.65–29.00 g/g) (Table 3), comparable to values reported for vegetable, fruit, and cereal fibers. High OHC enhances the sensory and functional properties of food products by improving tenderness and fat

binding, while also contributing to cholesterol reduction and obesity prevention by binding bile acids and fats in the gastrointestinal tract (Tosh and Yada, 2010).

GAC is a functional property relevant to glycemic control, was significantly higher in PPMF compared to OPT, likely due to its greater IDF content (Table 4). The GAC values align with those reported for other dietary fibers such as algae, carrot, and garlic straw (He *et al.*, 2022). This property supports the potential of PPMF to modulate glucose metabolism through adsorption and fermentation-mediated short-chain fatty acid production, which stimulates satiety hormones and insulin secretion, thereby aiding in blood glucose regulation (Zhao *et al.*, 2018).

The inhibition of α-amylase, an enzyme critical for carbohydrate digestion, was notably higher in PPMF than OPT (Table 4), and both exceeded the inhibitory activities reported for dietary fibers from other food sources, which generally range between 6.33 % and 31.03 % (Daou and Hui, 2014; Ma and Mu, 2016; Zheng and Li, 2018). This suggests a superior capacity of PPMF to reduce postprandial glucose spikes, supporting its potential as a functional food ingredient to mitigate the risk of type-2 diabetes.

TABLE 4. Glucose adsorption capacity (GAC) and alpha-amylase inhibitory activity of palm-pressed mesocarp fiber and oil palm trunk

	PPMF	OPT
Glucose adsorption capacity (GAC), mmol/g	2.09 ± 0.39^{b}	0.44 ± 0.22^{a}
Alpha-amylase inhibitory activity, %	65.79 ± 4.26^{b}	41.23 ± 1.52^{a}

Note: Each data represents the mean ± SD of three independent experiments where means with different letters in the same row indicate significant differences ($p < 0.05$) based on multiple independent (unpaired) t-tests. PPMF: palm-pressed mesocarp fiber; OPT: oil palm trunk.

The marked differences in proximate composition and functional properties between PPMF and OPT demonstrate the variability within OPB, underscoring the importance of targeted valorization strategies. The notably high insoluble dietary fiber content and functional properties of PPMF position it as a promising alternative dietary fiber source with significant health-promoting potential.

From an industrial perspective, the physicochemical characteristics of PPMF suggest multiple applications. Its high water retention and swelling capacities enable its use as a moisture-retaining agent and texturizer in food formulations, while its substantial OHC makes it suitable for improving fat binding and mouthfeel in processed foods. Such properties are advantageous for developing fiber-enriched functional foods, meat analogues, and emulsified products.

Moreover, the functional health-related attributes of PPMF, particularly its glucose adsorption and α-amylase inhibitory activities, highlight its potential role in glycemic regulation. The ability to modulate postprandial blood glucose through these mechanisms supports further exploration of PPMF as a functional ingredient in diabetes management and metabolic health.

OPT, while differing in composition, also exhibits promising dietary fiber content and functional properties, reaffirming its potential value beyond traditional uses. Together, these OPB can be valorized as sustainable, cost-effective sources of dietary fiber and functional bioactives, contributing to circular economy initiatives within the palm oil industry.

4. CONCLUSIONS

This study characterized PPMF and OPT as alternative DF sources derived from abundant oil palm biomass residues in Malaysia. Both PPMF and OPT demonstrated exceptionally high insoluble dietary fiber content, surpassing common food sources, alongside favorable physicochemical properties such as water retention, swelling, and oil holding capacities. Importantly, PPMF exhibited superior glucose adsorption capacity and α-amylase inhibitory activity, indicating strong potential to aid in blood glucose regulation and metabolic health. These findings support the incorporation of PPMF and OPT into functional food formulations, addressing the increasing need for sustainable fiber sources amid low DF intakes and growing health concerns such as diabetes. Valorizing these oil palm by-products aligns with the goals of sustainable industrial practices, promoting added-value utilization of residues while contributing to improved public

health outcomes. Future work should focus on in vivo evaluations of the metabolic benefits and food application trials to fully harness the potential of PPMF and OPT as functional ingredients in the food and nutraceutical industries.

RESEARCH DATA POLICY

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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We would like to thank the Director-General of MPOB for his permission to publish these data.

DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

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AUTHORSHIP CONTRIBUTION STATEMENT

SS Teh: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. HLN Lau: Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing.

ARTIFICIAL INTELLIGENCE USAGE

Artificial Intelligence tools were used in the preparation of this manuscript to assist with language editing and improving clarity. All intellectual content, analysis, and conclusions are the result of the authors' work.

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