

Contents and Utilization of Palm Oil Fruit Waste

Melvia Sundalian ^{1,*}, Dhia Larissa ¹, Oo Suprijana ¹

¹ Sekolah Tinggi Farmasi Indonesia, Bandung, Indonesia; melviasundalian@stfi.ac.id (M.S.), dhialarissa@gmail.com (D.L.), oosuprijana@stfi.ac.id (O.S.);

* Correspondence: melviasundalian@stfi.ac.id;

Scopus Author ID 57212552414

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Abstract: Oil palm (*Elaeis guineensis* Jacq) is a part of the family of *Arecaceae*, which originated from West Africa. Oil palm can be grown in the tropics of Asia, Africa, and Central and South America. Palm oil produces two types of oil: Crude Palm Oil (CPO) and Palm Kernel Oil (PKO). Indonesia's CPO production reaches 49 million tonnes in 2020. This production produces around 35-40% of waste. Fresh Fruit Bunch (FFB) is extracted into Crude Palm Oil (CPO) and Palm Kernel Oil (PKO), which produce waste such as Palm Oil Mill Effluent (POME), Empty Fruit Bunch (EFB), Mesocarp Fiber (MF), Palm Kernel Shell (PKS) and Palm Kernel Meal (PKM). Palm oil production increases every year, which causes the waste from the industry to increase too. Palm oil waste still has chemical content that is good enough to be utilized. The study was conducted online at Google Scholar and PubMed by reviewing literature from domestic and international journals and research reports. The results showed that each waste contains different content, including carbohydrates, protein, fat, lignin, cellulose, mannose, and others. This waste has also been used in various fields. This waste has also been used for livestock, fuel, and raw materials.

Keywords: palm oil waste; contents; utilization.

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1. Introduction

Oil palm (*Elaeis guineensis* Jacq) is a part of the family of *Arecaceae*, which originated from West Africa. Oil palm can be grown in the tropics of Asia, Africa, and Central and South America. The development of oil palm plantations in Asia started in the Botanic Gardens in Bogor, Indonesia, where the oil palm seed was introduced from Mauritius and Amsterdam [1]. Data from the Directorate General of Plantation, Ministry of Agriculture of Indonesia, from 2014 to 2018, the total area of oil palm increased by 3,571,549 hectares [2]. Indonesia has become the world's leading producer of crude palm oil with the production of 23.9 million tonnes in 2011; Indonesia contributed 49.7% of world production, followed by Malaysia (37.8%), Thailand (3.2%), Nigeria (1.8%), and Colombia (1.7%) [3].

Palm oil produces two types of oil: crude palm oil (CPO) and palm kernel oil (PKO) [4]. Palm oil is one of the most consumed oils in the world. This cheap and easy to produce oil is used for a wide variety of foods, cosmetics, cleaning agents, and others. Malaysia and Indonesia are the largest producers of palm kernel oil, while the Philippines and Indonesia are the largest producers of crude palm oil (CPO) [5]. The potential for oil palm in Indonesia is very large; the palm oil industry has grown to 608 industries in 22 provinces. Data from the Directorate General of Plantation, Ministry of Agriculture of Indonesia 2020, show that Indonesia's CPO production reached 42.9 million tons in 2018 and is expected to reach 49

million tons by 2020 [2]. On the other side, this product will produce around 35-40% of waste, so that is estimated there will be 19.6 million tons of waste by 2020. Palm oil production increases every year, which causes the waste from the industry to increase too [4]. In fact, palm oil waste still has chemical content that is good enough to be utilized.

There are two processes for extracting palm oil from Fresh Fruit Bunch: chemical extraction using solvents and physical extraction with an emphasis on oil palm. Extraction with emphasis is an extraction that is widely used because of the easy process and cheap. However, in processing oil palm, it will leave a residue known as palm oil waste. Waste from oil palm processing has the potential to be utilized if managed properly. There are two types of palm oil production waste, liquid waste such as Palm Oil Mill Effluent (POME), and solid waste such as Empty Fruit Bunch (EFB), Palm Kernel Meal / Palm Kernel Cake (PKM), Mesocarp Fiber (MF), and Palm Kernel Shell (PKS) [4], [6], [7].

The composition of the waste varies depending on the season and the quality of the raw materials. POME, with its organic content, is commonly used for biogas production [8]. EFB contains nanocellulose, which are useful in the pharmaceutical and food fields [9]. EFB can also produce activated carbon and is used as an adsorbent, such as MF and PKS [10]–[14]. PKC contains *D-mannose*, which has a wide application in the pharmaceutical industry, in the food and feed industry [15] and has an important role in human metabolism. *D-mannose* has been shown to prevent recurrent urinary tract infections [16]. There have been several studies conducted to analyze the chemical content of PKC. PKC from the screw extraction process or pressing the palm kernel contains carbohydrates, protein, crude fiber, and oil, as well as crude fat. PKC can be explored as a potential source of important components for human nutrition [5], [17].

From the background presented, seeing the great potential of palm oil waste as a source of nutrition for health and a source of raw materials in the pharmaceutical sector, this article aims to gather information regarding the content of some oil palm waste and its benefits so that it can be used for the future development of palm oil waste.

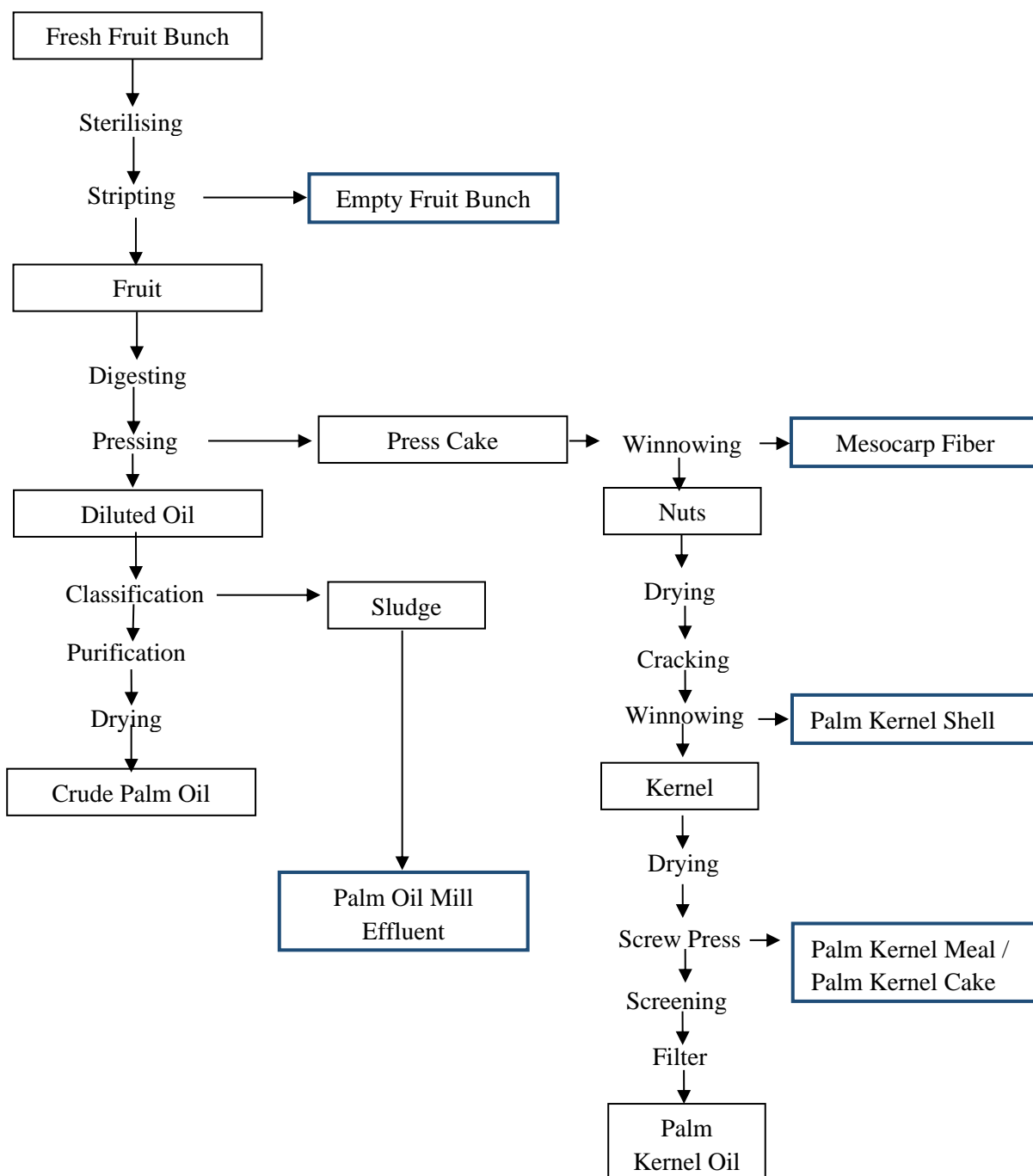
2. Materials and Methods

Research Conducted online at Google Scholar. The research was conducted in Indonesian and English. Literature reviews were obtained from domestic and international journals and research reports in March-August 2020. The number of literature reviewed was 65 journals.

3. Results and Discussion

Oil palm (*Elaeis*) is an industrial plant as a raw material for producing oil belonging to the family *Arecaceae*, which consists of two species, one of them is African Palm Oil (*Elaeis guineensis* Jacq). Palm oil produces two types of oil: crude palm oil (CPO) and palm kernel oil (PKO) [4]. Palm oil is one of the most consumed oils in the world. This cheap and easy to produce oil is used for a wide variety of foods, cosmetics, cleaning agents, and others [5]. Palm oil has the same amount of saturated and unsaturated fatty acids. Palmitic acid is saturated fat, while oleic acid is an unsaturated fatty acid. With around 500-700 ppm of carotenoids, palm oil is the richest source of β -carotene. This oil is also very rich in vitamin E, especially tocotrienols and tocopherols. Carotenoids and vitamin E act synergistically as a powerful natural antioxidant [18].

There are two processes for extracting palm oil from the Fresh Fruit Bunch (FFB), namely, chemical extraction using solvents and physical extraction with an emphasis on oil palm. Extraction with emphasis is an extraction that is widely used because of the easy process and cheap. However, in processing, palm oil will leave a residue that is commonly known as palm oil [4]. The flow chart for processing FFB into CPO and PKO is depicted in Scheme 1.



Scheme 1. Flow Chart of FFB processing into CPO and PKO [4], [21], [23], [24].

3.1. Contents of palm oil waste

3.1.1. Palm oil mill effluent (POME)

POME is liquid waste from the palm oil production process. Typically, POME is produced from plant operations at temperatures between 80°C and 90°C. The characteristics of POME depend on the quality of the raw material and the oil production process in palm oil

mills. POME is acidic (pH 4-5). POME is thick brown in color, which contains a high concentration of organic compounds [19]–[21]. POME accounts for the largest portion of all waste generated in the FFB extraction process [22]. POME has high carbon and hydrogen content, as well as low nitrogen and sulfur content [20]. Heavy metals, such as Pb, can also be in POME, but their concentrations are below sublethal levels ($> 17.5\mu\text{g} / \text{g}$). Pb is commonly found in POME as contamination from plastics, metal pipes, and tanks, where Pb is widely used in paints and glass materials [21].

The high concentration of carbohydrates, protein, lipids, and minerals are present in POME. It makes a good raw material for biological conversion through various processes biotechnological. Table 1 shows the direct composition (%) of the main constituents of POME.

Table 1. Chemical Component of Palm Oil Mill Effluent.

Component	Range
Moisture	6.99
Crude Protein	12.75
Crude Lipid	10.21
Ash	14.88
Carbohydrate	29.55
Total Carotenoid	0.019 [25]

POME contains carotenoid, which is isolated by column chromatography method with n-hexane and petroleum ether solvents [19, 26]. However, n-hexane is a better solvent than petroleum ether in pulling compounds from POME. The carotenoid concentration obtained from POME is from 390-1450 ppm. The main component of POME is similar to CPO, which contains α -carotene and β -carotene. The percentage of β -carotene was higher than α -carotene, with a ratio of 7: 3 of POME [26]. α -carotene and β -carotene function as antioxidants and anti-inflammatory properties [27, 28]. Carotene intake can help rejuvenate the body by promoting the growth of healthy body cells and inhibiting the growth of unhealthy cells. This carotene contributes to preventing degenerative diseases such as cardiovascular disease, diabetes, and some types of cancer [27].

3.1.2. Empty fruit bunch (EFB).

In the extraction process of Crude Palm Oil (CPO) from the Fresh Fruit Bunch (FFB), it produces not only POME, but also Empty Fruit Bunch (EFB). As much as 25-26% of total CPO production is EFB [29]. However, only about 10% is used for fuel and compost; the rest is still waste [9]. EFB is composed of several important substances that can be used as other materials of economic value. Its main components include cellulose, lignin, holocellulose, hemicellulose, water, and other substances [29]. The chemical components of EFB can be seen in Table 2.

Cellulose and Nanocellulose were successfully extracted from EFB [9, 31]. Nanocellulose is produced by hydrolyzing EFB with sulfuric acid. The hydrolysis time is an important factor in changing the properties of nanocellulose. The best time to isolate nanocellulose from EFB using sulfuric acid hydrolysis is 60 minutes [31]. Cellulose and nanocellulose are classified as safe for processing and consumption. Cellulose and some of its derivatives are FDA approved as additives in food and medicinal products [32].

Table 2. Chemical component of Empty Fruit Bunch.

Komponen	Kadar (%)
Moisture	2.44 -15.01
Lignin	23.9 – 25.83
Holoselulosa	56.49
Selulosa	33.25
Hemiselulosa	23.24
Ash	4.48 – 5.26
Karbon Tetap	0.98 – 18.67
Volatile Matter	73.63 – 79.58 [6], [11], [29]
Glucan	31.4 [30]
Xylan	18.6 [30]
Arabinan	2.7 [30]

EFB contains carbohydrates that consist of several components, as in table 2, one of which is xylan [30]. Xylan is a pentose or xylose polymer with B-1,4 bonds whose monomer numbers range from 150-200 units. Xylan has many benefits as an industrial raw material, including as a thickening agent (thickener) and as a raw material for making films. In addition, xylan is also used as an endo-B-1,4-D-xylanase substrate. Endo-B-1,4-D-xylanase hydrolyzes xylan to xylooligosaccharides and xylose [6]. Xylooligosaccharides are very beneficial for health, namely stimulating the growth of bifidobacteria in the human gut so that xylooligosaccharides are considered prebiotics [33].

Palm oil waste as a biomass resource in Indonesia has not been fully utilized. One of the products that can be made from oil palm biomass as activated carbon [34]. EFB is a potential precursor for activated carbon production. Several studies have shown that EFB can be used as an adsorbent to remove heavy metals such as Hg (III), Pb (III), and Cu (III). Characterization studies indicate that the use of activated carbon-zinc chloride has a yield (37.9%), carbon content (87.15%), and surface area (86.62 m²/ g) was higher than activated carbon without chemical activation [12]. The surface area of activated carbon using the BET gain is as high as 720 m²/ g. This value is still included in the commercial activated carbon range (500-1500 m²/ g) [11]. Meanwhile, the surface area of activated carbon activated by KOH was 807.54 m²/ g [10]

3.1.3. Mesocarp fiber (MF).

Mesocarp fiber has a hard and strong texture [35]. As much as 13% of total coconut oil production is a by-product, namely Palm Fiber [36]. Chemical components of Mesocarp Fiber are in Table 3.

Table 3. Chemical component Mesocarp Fiber.

Component	Range
Cellulose	42.7-65
Lignin	13.2-25.31
Hemicellulose	17.1-33.5
Holocellulose	68.3-86.3
Ash Content	1.3-7.90 [6], [35]
Moisture	11.10 [6]
Pentosan	17.8-20.3
Arabinose	2.5
Xylose	33.1
Mannose	1.3
Galactose	1.0
Glucose	66.4 [35]

Mesocarp fiber is rich in lignocellulose. There is potential for the production of nanocellulose from MF for various applications, especially for nanocomposite materials as reinforcing materials for the automotive industry, especially for interior applications, construction, electronics, cosmetics, packaging, and also for biomedical purposes [35].

3.1.4. Palm kernel shell (PKS).

Palm Kernel Shell is one of the wastes from palm oil production that comes from separating Nuts from Kernel [36]. PKS usually accounts for 7% of the total palm oil production [36]. Palm shells are used to prepare activated carbon using potassium carbonate (K_2CO_3) as an activating agent [14]. The components of the Palm Kernel Shell can be seen in Table 4.

Table 4. Chemical component of Palm Kernel Shell.

Component	Range
Cellulose	29.70
Lignin	53.40
Holocellulose	47.40 [37]
Ash Content	1.10-3.24
Moisture	7.96-10.23
Volatile	0.10-85.11
Carbon	1.42-18.70 [6], [37]

3.1.5. Palm kernel meal (PKM).

PKO is extracted from the kernel mechanically through pressing or solvent extraction. However, due to difficult solvent recovery and safety concerns, solvent extraction is rarely used. Mechanical extraction is more commonly used because it is relatively easy and cheap [4]. From the mechanical extraction method, the results of the proximate analysis of the kernel before extraction and the palm kernel cake, the waste from the extracted kernels are in table 5. Several studies of several beneficial wastes are shown in table 6.

Table 5. Comparison of Proximate Analysis of Kernel and Palm Kernel Meal.

	Kernel	Meal
Oil content	49	7.9
Protein	8.3	14.8
Crude Fiber	8.1	16.7
Moisture	6.5	6.4
Ash	2.0	3.9
Carbohydrate	26.1	50.3 [5]

Table 6. Chemical component of Palm Kernel Meal.

Component	Range
Carbohydrate	50.3 – 50.4
Protein	14.8 -19 [5], [17], [36]
Crude Fiber	11.5 – 16.7
Oil Content	5.5 – 7.9
Moisture	6.4 – 8.9
Ash	3.9-6.1 [5], [17]

Along with the increase in palm kernel oil production, there is also an increase in the amount of PKM waste produced. The proportion of PKM is 45-46% of the palm kernel [38]. PKM has the potential to be reused because it contains protein between 14.19% -21.66%, fat 9.5% -10.5% and crude Fiber 12.63% [38]. Several technologies can be used to increase the value of PKM, namely chemically with immersion technology in acids or alkalis [1, 38]. Through chemical engineering, crude fibers from PKM materials can be derived by immersion with acetic acid and formic acid or alkalis (ammonium hydroxide) [1]. The decrease in fiber

content can be done by immersion in alkaline, because the absorption of alkali into the cell wall of the material then breaks the ester bonds in the chains of lignin, hemicellulose, and cellulose, which causes the cell wall structure to be simple [38]. PKM processing can also be done physically with filtering technology. Filtering is a simple way that can reduce crude fiber in PKM [39].

PKM is rich in nonstarch polysaccharides with the main structure galactomannan, glucomannan, and manan with a manan content of about 35.2%. Manan is a polymer of D-mannose with β 1,4 and D-galactose chains, which are difficult to degrade, but when degraded, it will become mannose compounds [38]. The PKM extraction process can be carried out using PKM that has been filtered by a smaller size of 850 μ m. The reduction in size, followed by hot water extraction, could increase the total amount of mannan extracted to 37% of the total CCP. The utilization of acetic acid shows that the total amount that can be extracted is relatively decreasing. This suggests that the use of acids under high-temperature conditions can damage the extracted sugar components [40].

Another content of palm oil cake is D-mannose. D-mannose is a hexose which has a wide application in the pharmaceutical industry, in the food and feed industry [15] and has an important role in human metabolism, especially in the glycosylation of certain proteins. D-mannose has been shown to prevent recurrent urinary tract infections [16]. PKM also showed the highest total phenolic content (5.35 mg / g) compared to other wastes. Pyrogallol, 4-hydroxybenzoic acid, gallic acid, and ferulic acid are the main compounds found in palm kernel cake extract [41].

3.2. Utilization of palm oil waste.

Palm oil production waste will continue to increase in line with the increase in world palm oil production. Therefore, the waste must be used according to its content. Several studies of several beneficial wastes are shown in table 7.

Table 7. Utilization of Palm Oil Waste.

Materials	Benefits
Palm Oil Mill Effluent	Alternative biomass fuels [8]
	Isolation or recovery of residual carotenes [19], [25], [26]
	Substrate for bioplastic production [25]
Empty Fruit Bunch	Hydrogel superabsorbent of cellulose EFB [42]
	Hydrogel of EFB nanocellulose [43]
	Nanocellulose EFB by hydrolysis of sulfuric acid, can adsorb selective metals such as Pb [44]
Mesocarp Fiber	Producing paper and paper powder [45]
	Animal feed [46]
	Alternative carriers in emulsion preparations [47]
Palm Kernel Shell	Isolated Fiber oil from Mesocarp Fiber [48]
	Metal adsorbent [49]
	Pyrolytic acid (PA) is used as an antioxidant, antibacterial, antifungal agent, and an alternative source for the production of anti-inflammatory drugs [50]
Palm Kernel Meal	Palm Kernel Meal High nutritious animal feed [36], [39]
	D-mannose isolation [15]

3.2.1. Palm oil mill effluent.

Palm oil waste is produced in large quantities in many developing countries. Its use is still limited; basically, it is used as food for animals or just as a landfill. However, they can serve as potential resources for use in several bioconversion processes to produce valuable

products. Efforts have been made to use POME in the production of value-added products; this helps in solving the pollution problems that may be caused by its disposal.

POME produced from the palm oil mill industry is considered as biomass waste, which can be fully utilized as a renewable energy source. This residue is converted into solid biomass fuel. The experimental results show that POME is feasible as an alternative biomass fuel [8], [20]. POME is also often used as a source of carotenes. This is because the POME waste still contains carotenes from the extracted coconut oil. The remaining carotenes and oil can be isolated or recovered from POME [19], [25], [26].

POME is also useful in the production of fertilizers [51], citric acid, bioethanol, biohydrogen, bioplastics, hydrolytic enzymes [25]. The high organic content of POME makes it a good substrate for bioplastic production. A two-stage process has been developed for the production of Polyhydroxyalkanoates (PHA) using POME. The initial stage involved the production of organic acids (acetic and propionic acids) by anaerobic treatment of POME, followed by the conversion of the resulting organic acids to PHA using the phototrophic bacteria, *Rhodobacter sphaeroides* (IFO 12203). POME used as a cheap carbon source to produce PHA can lead to some significant economic benefits [25].

3.2.2. Empty fruit bunch.

EFB can be used as a hydrogel superabsorbent. The superabsorbent hydrogel is made from a mixture of EFB cellulose and carboxymethylcellulose (Na CMC). The hydrogel is a polymer gel obtained from synthetics and/or natural polymers that can be produced from cellulose. This material can absorb and hold a lot of water. To increase the swelling ability of the cellulose hydrogel, a cellulose derivative such as sodium carboxymethyl cellulose (NaCMC) can be added [42]. The hydrogel can also be made with Nanocellulose from EFB [43]

EFB-based nanocellulose (NC) was successfully produced as a super-adsorbent for water remediation by hydrolysis of sulfuric acid (NCS) and phosphate (NCP) and functioned with carbon (AC). The formation of sulfonic groups on the NCS surface can achieve a higher remediation ability than EFB-NCP. In a very short time, 2 wt% of the formulated super-adsorbent EFB-NCS demonstrated selective and excellent metal adsorption ability against Pb [44]. Microcrystalline cellulose silylation (MCC) was isolated from EFB using aminosilane compounds that were synthesized by aminolysis of 3-glycidoxypropyltrimethoxysilane (GPTMS) with ethylenediamine (EDA) [52].

EFB can be used for the production of lignocellulosic bioethanol. To increase the productivity of ethanol with EFB with high lignin content, biomass was prepared by alkaline-thermal pre-treatment (sodium hydroxide, 121°C, 60 minutes) [53], [54].

3.2.3. Mesocarp fiber.

Mesocarp Fiber is a by-product of palm oil production. A number of approaches to process a large number of palm oil mill by-products into value-added products have been implemented. Mesocarp fiber can be utilized to produce paper and paper powder [45], animal feed [46], and as an alternative carrier in emulsion preparations [47].

Fiber oil is extracted from Mesocarp Fiber using supercritical carbon dioxide and solvents [48]. The recovery rate and the fatty acid composition of the fiber oil were compared between three different extraction methods, namely Soxhlet extraction, reflux, and cold

methods. However, the ones that produced the highest yield were the cold method, then reflux, and the last one was soxhlet [55]. Fiber oil-based emulsion has good stability, no significant separation of oil and water phases. Therefore, fiber oil is good to be used as an alternative carrier oil in treatment product formulations [47].

3.2.4 Palm kernel shell.

Heavy metal contamination in water causes adverse effects on human health. Millions of tonnes of PKS are produced as waste from oil palm plantations every year. PKS is used as an effective adsorbent to remove heavy metals, namely; Cr^{6+} , Pb^{2+} , Cd^{2+} and Zn^{2+} from water. This PKS is also used as an adsorbent without pre-treatment with acid/base, just used with water and after drying and grinding, it is immediately applied for adsorption of metal ions [49].

PKS is also used to prepare activated carbon, which is tested to remove dyes from water. The adsorbent was prepared by 1 hour of PKS impregnation with ZnCl_2 as the activating agent (PKS: ZnCl_2 mass ratio 1: 1 and 2: 1), followed by carbonization in an autogenous atmosphere at 500°C and 550°C for 1 hour [56].

Pyroligneous acid (PA) obtained from the slow pyrolysis of palm kernel shells (PKS) has a high total phenolic content and exhibits various biological activities, including antioxidant, antibacterial, and antifungal. PA obtained by slow pyrolysis method and fractionated using column chromatography. PA from PKS has the potential to be used as an alternative to antioxidant and anti-inflammatory agents that are biodegradable, cheaper, and safer for the environment. Chemical tests and molecular docking studies add to the pharmacological justification for using MCC as an alternative source for the production of anti-inflammatory drugs. Nevertheless, more research needs to be done before commercialization efforts [50], [57].

3.2.5. Palm kernel meal.

The most widely used PKM is as animal feed. PKM is used to feed livestock because of its nutritional content [36]. To increase the nutritional value of palm kernel cake, it can be done by reducing the PKM shell or adding enzymes. The reduction of PKM shells is quite effective with the filtering technique with a 2 mm diameter filter. This process can reduce the shell content in PKM by up to 50%. The addition of enzymes increases the digestibility of nutrients (dry matter, metabolic energy, and protein) PKM. The best increase in nutrient digestibility was obtained from the addition of the enzyme Balitnak (BS4) production at a dose of 20 ml/kg of palm oil cake. This increase in digestibility was as effective as the addition of commercial (multi) enzymes at a dose of 2g/kg of palm kernel meal. Therefore, the filtering process followed by the addition of BS4 enzymes or commercial multi-enzymes to PKM can increase its content [39].

PKM contains high carbohydrates. D-mannose was isolated from PKM. PKM is catalytically hydrolyzed with sulfuric acid at 100°C and then fermented by the mannan-degrading enzyme. The solution after fermentation undergoes filtration in a silica gel column, desalination by ion-exchange resin, and crystallization in ethanol to give pure D-mannose in a total yield of 48.4%. D-Mannose is a hexose that has wide applications in the pharmaceutical industry, in the food and feed industry, and in biological research [15].

D-mannose is used as an inexpensive starting material for the synthesis of immunostimulating agents [58], antitumor agents [59], vitamin [60], and d-mannitol [61].

Currently, the biotransformation of mannitol from Indonesia, d-mannose, is a new production trend for mannitol. The reduction of d-mannose with sodium borohydride or electrolysis leads to a high d-mannitol yield of more than 31% [62]. D-Mannitol is used in the synthesis of drugs such as oseltamivir phosphate [63] and newer drugs against AIDS [64].

PKM has similar content to aloe vera (Aloe Vera), which is good for health and beauty, and its function is closely correlated with the presence of mannose-rich polysaccharides [65]. Likewise, for d-glucose, d-fructose, d-ribose, and d-xylose, d-mannose is a moisturizing addition agent that is widely used in skincare products. d-mannose units are linked to each other by β -glycosidic bonds (1-4). d-Mannose exhibits outstanding moisturizing and tasting abilities, and leaves skin less tight, less dry, and more moisturized [64].

4. Conclusions

CPO and PKO production processes will produce by-products in the form of waste originating from the Fresh Fruit Bunch. These wastes include POME, EFB, MF, PKS, and PKM. The waste contains different content, including carbohydrates, protein, fat, lignin, cellulose, and mannose. This waste has also been used in various fields. This waste has also been used for livestock, fuel, and raw materials.

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Conflicts of Interest

The authors declare no conflict of interest.

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