Empty fruit bunches, potential fiber source for Indonesian pulp and paper industry

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Abstract. Empty fruit bunches (EFB) is one of solid waste from crude palm oil (CPO) mill. It's about 20-22% from fresh fruit bunches (FFB) or equal to the CPO yield. Indonesian CPO production in 2019 was 51.8 million tons; increased by 9% compared to 2018. So, about 51.8 million tons of EFB was available in 2019. EFB is a potential lignocellulosic material for pulp and paper. The utilization of EFB fibers for papermaking has been studied extensively. The use of EFB for printing and writing papers tends to cause pitch problems and poor visual appearance. The most potential use of EFB fibers is for packaging papers. EFB fiber is classified as short up to moderate fibers, so its usage must still be mixed with other fibers to improve the sheet strength. Many experiments have been done regarding the mixture of EFB fibers with other fibers such as OCC (Old Corrugated Containers) and UBC (Used Beverage Cartons) recycled fibers. Other types of paper from EFB are still being developed, including for nursery bags and active packaging papers.

1. Introduction
Indonesian pulp and paper industry experienced a period of very rapid growth in the era of 80s. At present, Indonesia has no less than 80 integrated and non-integrated pulp and paper industries spread across Java, Sumatera, and Kalimantan islands. Indonesian pulp and paper production ranks 10th in the world for pulp and 6th for paper. Whereas in Asia it is ranked 3rd for pulp and 4th for paper [1].

Overall, Indonesian paper production in the last few years increased, especially for industrial paper types. Based on the data from Indonesian Ministry of Industry, in 2019, the industry of paper, paper goods, printing, and reproduction of recording media grew by 8.86%. This growth must be supported by the sustainable availability of its raw materials, especially fiber which is the largest proportion in papers (70-95%) [2].

The fiber source for paper can be generated from wood, non-wood, or secondary fibers from recycled papers. For the printing paper industry, the need for bleached short-fiber wood pulp can be fulfilled by the local pulp mills which generally using Acacia and Eucalyptus as their raw material [3]. Whereas long fiber wood pulp both bleached and unbleached is obtained from imports. Almost all packaging paper industry uses secondary fibers from recycled paper. Even if there is a slight use of unbleached long fiber wood pulp, this pulp is fully obtained from imports [4].

In recent years, the need for recycled paper increased in line with the increasing packaging paper production [5]. In addition to facing unstable paper quality problems due to the variety of recycled paper quality used, the packaging paper industry is also faced with the problem of supply of recycled paper
that is constrained by the inadequately of local recycled paper availability, so that must be obtained from imports. The increasing stringent regulations on an imported recycled paper have made the availability of imported used paper even more limited [6]. Therefore, the sustainable alternative sources of fiber for pulp and paper is needed.

Indonesia has a lot of non-wood fiber sources for pulp and paper; some of which have been used commercially such as straw, bagasse, and bamboo. However, due to its decreasing availability, there are no more pulps that are produced from non-wood raw materials. Some non-timber plants also have potential such as abaca, flax, kenaf, roselle, and many more [7], but until now they have not been produced commercially due to the insecure sustainability of its' supply.

Oil palm empty fruit bunches are one of the solid wastes produced from CPO (crude palm oil) mills which have not been utilized commercially. Currently, its use is only limited as fuel at the CPO mill itself or as compost in oil palm plantations. Even though it has been known that EFB is a potential lignocellulosic material for pulp and paper [8], it is still not utilized commercially. In the future, oil palm empty fruit bunches are expected to be a potential alternative of non-wood raw material [9-13]. Especially for pulp and paper manufacturing, there have been many studies conducted, even in Malaysia, there have been industries that process oil palm empty fruit bunches commercially as raw material for pulp and paper [10,14].

Indonesia, as the largest palm oil-producing countries in the world, has the opportunity to utilize this oil palm empty fruit bunches as raw material for pulp and paper. This paper outlines how big the potential of EFB is in Indonesia and some types of paper that can be produced from EFB fibers [11,15].

2. Availability of EFB in Indonesia

Oil palm is one of the commodities of plantation products that has an important role in economic activities in Indonesia because of its ability to produce vegetable oil which consists of crude palm oil (palm oil obtained from the extraction or pressing of oil palm fresh fruit bunch) and palm kernel oil (palm kernel oil). As the largest palm oil-producing country in the world, the plantation area and production of oil palm in Indonesia continue to increase (figure 1). The oil palm plantation in Indonesia is spread in 25 provinces. However, only five provinces are the largest palm oil producers, respectively starting from the highest production capacity namely Riau, Central Kalimantan, North Sumatra, West Kalimantan and South Sumatra provinces [16].

**Figure 1.** Growth of area and production of oil palm plantations Indonesia, 2014-2018 [16].

From figure 1 above, it can be seen that over the past five years, CPO production has increased by almost 25%. From the processing of oil palm fresh fruit bunches (FFB), several side products that are potential to provide added value are generated, including empty fruit bunches (EFB). In figure 2, it can be seen that the mass balance in the processing of oil palm fresh fruit bunch. As a side product, the amount of EFB generated is almost the same as the amount of crude palm oil produced [12]. Each processing of 1 ton of fresh fruit bunches will produce 21–23% of oil palm empty fruit bunches or 210-
230 kg [17,18]. From figure 1, it can be predicted that the number of EFB obtained will be around 8.0498 million tons during 2018 or equivalent to 26,830 tons/day.

![Figure 2](image1.png)

**Figure 2.** Mass balance in palm oil fresh fruit bunch processing [17].

3. **Characteristics of EFB fibers**

The characteristics of fiber affect the properties of paper/paperboard produced and the ease of fiber to be processed before it is formed into paper or paperboard. The morphological and chemical characteristics of EFB fibers, and how it affects the pulp and paper produced are discussed in the following description.

![Figure 3](image2.png)

**Figure 3.** Three types of EFB fibers [19].

There are 3 forms of EFB fibers based on the number of ripe fruits in fresh fruit bunches (FFB), i.e. type 1, type 2, and type 3 as shown in figure 3. In type 1, the percentage of ripe fruit is only 40%, while type 2 and type 3 have 75% and 90% of ripe fruit respectively. These forms affect the integrity and compactness of the EFB and whether or not the EFB is easy to be deciphered. The more ripe fruit in the EFB, the easier it is to be deciphered [20].

Bulk density of EFB is 177.98 kg/m³ [19], lower than that of *Acacia mangium*, i.e. 461 kg/m³ [21], 390 kg/m³ [22], or *Acacia auriculiformis*, i.e. 410 kg/m³ [22]. Fiber and non-fiber content of EFB are 72.67% and 27.33% for the base section of EFB, and 62.47% and 37.53% for the tip of EFB [19, 23-24].

3.1. **Fibers morphology**

The morphology EFB fiber is shown in table 1. It can be seen that the average of EFB fiber length is in the range of 0.76 mm up to 1.81 mm. Based on IAWA (International Association of Wood Anatomy) classification, EFB fiber is classified as very short (0.5-0.7 mm) up to moderate (0.9-1.6 mm) fiber [11].
The average fiber length of EFB is 0.87 mm and the largest proportion, i.e. about 91%, is in the range of 0-1 mm [25].

The EFB fiber length is also affected by the pulping process. The average fiber length of EFB semi-chemical pulp is 0.767 mm, while the EFB thermo-mechanical pulp is 1.023 mm at the temperature of 166°C with hot air-dried, and 0.737 mm at 140°C with warm air-dried. Meanwhile, the EFB chemical pulp with Kappa number of 9.6 and yield of 31.1% has a low average fiber length of 0.556 mm [26].

The fiber length is the main morphological characteristics of a fiber since it affects the sheet strength. The longer the fiber, the higher the strength. The Runkle ratio of EFB fiber is 0.94, lower than 1. This indicates that EFB fiber has a high lumen diameter with a thin wall. It means that the EFB fiber can be easily flattened during the refining process. Muhlstep ratio and felting power of EFB fibers, namely 73.48 and 53.0-79.95 respectively shows that the EFB fiber is easy to flatten and form inter-fiber bonding [27]. In general, the morphology of the base section of EFB fiber is better than its tip section [19].

Although Acacia wood species is classified as short fibers, the average fiber length is slightly higher than EFB fibers (table 2). The lumen diameter is much greater than that of the EFB fiber. With the lower fiber wall thickness, the Runkle ratio of Acacia wood species is much lower than that of EFB fiber. This
shows that the fiber of Acacia wood species is easier to be refined compared to EFB fiber. The felting power of EFB fiber is almost the same as Acacia wood species, but the Muhlstep ratio is almost twice. The Muhlstep ratio affects the ability of fiber to be flattened in the refining process. The lower the Muhlstep ratio, the easier the fiber to flatten so that the refining process becomes easier [27].

Compared to wheat straw fiber, EFB fiber length is lower, with a Runkle ratio below 1. While, the wheat straw fiber has a Runkle ratio of greater than 1, which indicates that the fiber will be difficult to flatten during the refining process. Wheat straw fiber has a higher felting power than EFB fiber [30]. The rigidity coefficient (W/D) of wheat straw fiber is 0.29, higher than EFB fiber (0.24). According to fiber requirements for pulp raw materials issued by the Directorate General of Forestry in 1976, fibers with a rigidity coefficient greater than 0.2 are included in the lowest grade (IV) [22].

### 3.2. Chemical composition
EFB has almost the same cellulose content as those of hardwoods, while lower in lignin content, and relatively higher in pentosans and hemicellulose content [31]. Table 3 shows the same tendency, with the extractive levels also almost equivalent. Compared to other non-wood fibers, EFB is relatively equivalent to bamboo except for the ash content, and quite equivalent to wheat straw but better than rice straw.

| Parameter         | Value               |
|-------------------|---------------------|
| α-cellulose, %    | 37.26-63            |
| Hemicellulose, %  | 14.6-37             |
| Pentosans, %      | 29.4                |
| Lignin, %         | 24-31               |
| Extractives, %    | 1.3-4.2             |
| Ash, %            | 1.2-6.7             |
| Wheat straw       | 39.8-43.2           |
| Hardwoods         | 28.95-34.2          |
| Bamboo            | 15.4-17.1           |
| Rice straw        | 19.8-21.12          |
|                   | 15.4-17.1           |
|                   | 22.7-35.2           |
|                   | 23.2-32.5           |
|                   | 28-36               |
|                   | 23-28               |
|                   | 12-14               |
|                   | 6.00-9.23           |
|                   | 0.5-2.9             |

Based on the classification of Indonesian hardwood chemical components established by the Ministry of Agriculture in 1976 [37], the classification of EFB chemical components can be seen in table 4.

From table 4, it can be seen that the cellulose content of EFB is a very wide range, ranging from high to low class. However, the general value is around 40% which shows that the EFB cellulose content is categorized in the moderate class. In terms of extractives content, EFB has relatively high extractives content. In the pulping process, it will cause an increase in the consumption of cooking chemicals and affects the quality of the paper produced.

| Parameter         | High | Moderate | Low |
|-------------------|------|----------|-----|
| Cellulose, %      | >45  | 40-45    | <40 |
| Lignin, %         | >33  | 18-33    | <18 |
| Pentosans, %      | >24  | 21-24    | <21 |
| Extractives, %    | >4   | 2-4      | <2  |
| Ash, %            | >6   | 0.2-6    | <0.2|

The unique characteristic of non-wood fibers requires special attention to the pulping process, including by conducting a pre-treatment before the pulping process. This pre-treatment can be in the form of physical/mechanical action, hydrothermal, chemical, and/or biological treatment. Each pre-treatment has a specific impact on the non-wood chemical contents such as cellulose, hemicellulose and lignin as well as other chemical components. However, the purpose of this pre-treatment is basically to
carry out further non-wood processing processes that are easier and more efficient as well as improves the quality of the final products [31]. Pre-treatment of EFB by immersing in sodium hydroxide solution in a certain concentration have been reported effective to increase to pulp yield of EFB refiner mechanical pulp (RMP) [41].

![Figure 4. EFB thermo-mechanical pulp.](image)

4. Paper products from EFB fiber

One of the potentials uses of EFB fiber is as pulp raw material for paper and paperboard. Before being made into paper, EFB fibers must first go through the pulping process. Experiments about EFB pulping have been carried out chemically, semi-chemically, and mechanically. Figure 4 shows the EFB pulp produced by thermo-mechanical pulping process. The EFB pulp bleaching process has also been investigated in both bio-bleaching and TCF (Totally Chlorine Free) processes [19]. The description below is limited to the explanation of some research results that have been carried out in relation to the use of EFB fibers in papermaking processes.

4.1. Writing and printing papers

Writing and printing paper is a type of paper used for writing and printing purposes. In addition, to fulfill the specified writing and printing properties, this type of paper must also have good aesthetic properties that are expressed in its optical properties. This paper is generally white, so it should be made from bleached pulp or deinked pulp from recycled fibers. The experiments of writing-printing papermaking from EFB bleached pulp mixed with deinked pulp have been done on a laboratory scale. In general, the quality of the paper produced was quite good, but the use of EFB pulp reduced the brightness of the sheet [42].

EFB fiber contains about 4.5% residual oil that found on the surface and tip of the fiber [43]. Actually, EFB does not contain oil, but in the process of boiling and releasing the fruit from its’ bunches in the CPO mill, the oil enters into the EFB by osmosis through the fiber wall [19]. The presence of oil content in EFB has the potential to pitch problems that cause stains and even a pinhole on the paper produced. Therefore, the oil content of EFB must be removed as much as possible. The pre-treatment of EFB fibers before the pulping process using lipase enzymes can be done to reduce this pitch problem [28,44]. Lypase enzyme can be utilized as well for pitch control in the papermaking process [45]. Besides, mechanical pitch removal using a multistage cleaning system can also be applied both in pulp mill and paper mill [46].

The experiments to improve the cellulose characteristics from EFB have been done extensively. A study regarding the recovery of high-purity lignin and cellulose from EFB using ethanol as a solvent has also been carried out [47]. The oxidation of EFB fiber using sodium hydroxide followed by the treatment with sodium hypochlorite increased the cellulose and hemicellulose content of pulp, while its' lignin content was decreased [48].

4.2. Packaging papers

Based on its fiber characteristics, the use of EFB fiber for paper packaging is considered the most appropriate. A fiber with high wall thickness tends to be more rigid so that their usage is more ideal for
corrugating medium paper or folded paper toweling [49]. Some research results in relation to this topic have been reported.

Industrial growth in Indonesia should be supported by the provision of industrial product packaging, including those made of paper and paperboard. The type of papers commonly used as raw material for industrial packaging are liner and corrugating medium paper. Liner paper is the inner and outer lining of a corrugated board which is a raw material for corrugated carton box while corrugating medium paper is a corrugated layer between two or more liner papers.

At present, the main raw material for liner and corrugating medium papers is recycled fibers from OCC (Old Corrugated Container). The main problem in the use of waste paper as a raw material for paper is the difficulty to obtain a stable and uniform quality due to the extremely varied quality of waste papers. This includes how many times the fiber from the waste papers has been recycled. EFB fiber is a very promising alternative as a substitute for recycled fiber [11,17,50].

The experiments on the manufacturing of liner and corrugating medium papers have been reported both at the laboratory and factory scale, as well as the manufacturing of corrugated board and corrugated carton boxes from those papers [19,20,28,51,52]. An experiment of liner and corrugating medium papermaking using EFB mechanical pulp has been investigated as well [23].

Generally, in those experiments, the EFB fibers were mixed with recycled fibers in various compositions, namely 50-60% EFB pulp for liner paper and 70-80% EFB pulp for corrugating medium paper, blended with OCC recycled fiber [20]; 6-50% EFB pulp blended with OCC recycled fiber for corrugating medium papermaking [52]; 25-75% EFB pulp blended with OCC, OCP (old copier paper) and ONP (old newsprint paper) recycled fibers [50]. The corrugating medium paper made from a mixture of EFB and OCC pulp is claimed to fulfill the specification of Indonesian National Standard (SNI) for corrugating medium-class B [20].

The manufacture of paper bags from EFB pulp has also been investigated. This type of papers is used as packaging for industrial products such as cement, or food products such as tea and sugar, or other materials in the form of powder [53]. In the experiment of cement sack papermaking, EFB pulp was added to substitute some of the unbleached long fiber pulp from Pinus radiata. The results showed that the use of 20% EFB pulp did not significantly affect the strength of the sheet.

The papermaking experiment from EFB pulp mixed with microbial cellulose (MC) from nata de cassava on various compositions have been also carried out [54]. The addition of MC from nata de cassava increased the strength properties of the paper sheet.

Mixing EFB fiber with UBC (Used Beverage cartons) recycled fibers can also be done since the UBC recycled fiber is categorized as high-grade fiber. UBC is a term for aseptic carton consisted of several laminated layers which have been used as a beverage packaging. It is a post-consumer waste which is consisted of paperboard (75%), and the rest of about 25% are polyethylene and aluminium foil. Since there is no contact between the beverage with the paperboard, so no wet strength chemicals are added. Therefore, the UBC repulping process in a paper mill can be done easily [55]. The use of EFB mixed with UBC recycled pulp for liner and corrugating medium papermaking has been tried and paper with good quality were resulted.

4.3. Other potential papers from EFB

In addition to its use for writing and printing as well as industrial papers, the following are some of the experiments that have been carried out and/or in progress related to the development of special papers from EFB.

4.3.1. Active packaging paper. Active packaging is one type of smart packaging commonly used as food product packaging with the aim of increasing durability and extending product shelf life while maintaining its quality [56]. Active packaging technology includes the ability to release or absorb the components from or into food products or the surrounding environment for the purpose of increasing the durability and extending the shelf life of food products [57].
The use of paper for active packaging has not been much developed yet, but its utilization as a passive packaging has been applied extensively, both for food and non-food products packaging. The research on the development of ethylene absorbent active paper has been carried out by superimposing specific chemical additives on the paper surface [58, 59]. Ethylene is a plant hormone in the form of gas which its level will increase with the increasing of plant maturity. In fresh fruits and vegetables, this hormone will trigger the process of ripening and aging so as to shorten the shelf life of fruits and vegetables. Therefore, the presence of ethylene in fruits and vegetables or in its surrounding environment should be controlled [60].

Corrugated carton boxes are widely used as fresh fruit and vegetable packaging. The control of fruit ripening or aging of vegetables is done by providing respiration holes on the walls of the box and storage in the controlled room condition. It has been previously discussed that EFB has the potential to be used as a source of fiber in the manufacture of liners and corrugating medium papers which are the raw materials for corrugated carton box manufacturing. The development of ethylene absorbent active paper made from EFB fiber, besides increasing the EFB added value as a by-product of CPO mill, it is also a challenge as well as an opportunity to support increased exports of Indonesian fruits and vegetables.

The use of EFB for manufacturing anti-microbial active paper has been reported. The experiments were carried out by mixing EFB pulp with citronella leaf pulp. Although the properties of the paper produced have not optimal yet, especially in terms of its strength, the paper showed a quite good anti-microbial properties and potential to be developed for food packaging paper [41].

The food packaging from EFB paper that is coated with chitosan has been developed. The chitosan coated onto paper surface increased the physical properties of paper, i.e. tensile strength, tensile modulus and elongation, and imparts antimicrobial properties, both Gram-positive and Gram-negative bacteria [61].

4.3.2. Nursery bag paper. The use of plastic packaging has become one of the contributors to environmental pollution that are quite troubling because it takes between 100-500 years to be decomposed perfectly. Indonesia is declared as the second-largest consumer country of plastic waste after China. Likewise, the use of polybags for nurseries on plantation and agriculture, or households needs, continue to increase and contribute to this pollution. Therefore, various efforts to control these surges have been made, including using packaging made from bio-plastic which is easier to decompose and/or paper.

Paper products have a high tendency to absorb liquid due to its lignocellulosic fiber content. Although these properties are useful for certain types of paper such as tissue, some paper products are required to be resistant to liquid penetration. Packaging paper is one type of paper that requires a certain level of resistance to water penetration, therefore the hydrophilic nature of the fiber must be controlled by the addition of certain chemicals that can resist water penetration into the paper [62].

Base paper for sacks (paper bag) must have sufficient strength properties to withstand the load in it. The strength of the paper is influenced by the type of fiber used and the inter fiber bond and the addition of reinforcing additives. In addition, paper bags must also be able to maintain its strength when it is wet, has a certain porosity/permeability, and especially for nursery needs, paper bags must be biodegradable and safe for the environment.

Utilization of unbleached EFB pulp mixed with other virgin pulp or recycled fibers in papermaking has been investigated. The results showed how potential the EFB as an alternative source of short fiber for paper [52,53,63]. Thus, EFB is a potential fiber source for nursery bag papermaking that more environmentally friendly instead of the polybag. Below are some pictures of EFB papers and paperboards (figure 5) and corrugated boxes produced from a mixture of EFB pulp and OCC recycled fiber (figure 6).
Experiments on the utilization of EFB fiber for dissolving-pulp has been carried out using soda-anthraquinone (soda-AQ) cooking process after being prehydrolysed at 150°C for 90-180 minutes. The optimum condition is achieved at prehydrolysis stage for 180 min followed by soda-AQ with alkali active of 20%. An EFB dissolving-pulp with kappa number of lower than 10 and high viscosity has resulted. However, the brightness of pulp still needs to be improved by using the proper bleaching process [64].

5. Conclusion
Up till now, the utilization of EFB for high value-added products has not yet been done commercially despite the potential availability of EFB in Indonesia from year to year continues to increase in line with the expansion of oil palm plantation and increasing CPO production. The utilization as a raw material for pulp and paper has been extensively studied both for writing and printing papers as well as for packaging papers, even some special types of paper from EFB have also started to be developed. With its high considerable potential of availability and promising research facts, EFB can be used commercially as an alternative raw material for the pulp and paper industry in Indonesia.

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In the Pulp and Paper Industry, the current state in Indonesia is characterized by the use of empty fruit bunches of plantation species as raw material for pulp and paper production. This practice has both advantages and challenges.

Advantages include the potential for increased use of local raw materials, reduced reliance on imported wood for pulp, and the potential for sustainable forest management practices. However, challenges exist, particularly in terms of production efficiency, quality control, and the need for infrastructure development to accommodate the increased use of these materials.

One study by Ali M M, Muhadi N, ‘Atirah, Hashim N, Abdullah A F and Mahadi M R (2020) highlights the optimization of empty fruit bunches (EFB) as a potential raw material for pulp production in Malaysia. The study found that EFB could be used as a substitute for wood chips in the production of Kraft liner and corrugating medium from mechanical pulping of EFB.

Another study by Tutik R, Siti P and Wiyarsi M A (2012) investigated the potential of oil palm empty fruit bunches as packaging papers raw material. They found that these materials could be used for the production of Kraft liner and corrugating medium from mechanical pulping of EFB.

Furthermore, the production of corrugated paper from the empty fruit bunches of oil palm has been explored, with studies showing potential for the development of a new packaging material.

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