
Analysis of Oil Palm Leaves Potential as an Alternative Raw Material for Paper Production

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ABSTRACT

The global paper industry faces a structural challenge due to excessive dependence on wood as its primary raw material, contributing to accelerated deforestation and tropical forest ecosystem degradation. Amid these environmental pressures, utilization of lignocellulosic biomass from plantation waste has emerged as a strategic and sustainable alternative. Indonesia, the world's largest palm oil producer, generates massive volumes of palm leaf waste that remain largely underutilized. This study aims to analyze the potential of oil palm leaves (*Elaeis guineensis* Jacq.) as an alternative raw material for paper production, encompassing biomass availability. An experimental laboratory approach was employed using NaOH delignification at 100°C for 60 minutes, followed by sheet formation and testing at two composition variants: 100% oil palm leaves and a 50% oil palm leaves–50% recycled pulp blend. The 100% leaf paper exhibited a coarser texture suitable for art and craft applications, while the blended composition produced more homogeneous sheets with superior mechanical strength for eco-packaging. These findings confirm that oil palm leaves represent a technically feasible, economically advantageous, and environmentally sustainable biomass feedstock as a partial wood substitute in the paper industry.

Keywords: Oil Palm Leaves; Oil Palm Biomass; Paper Pulp; Sustainability Plantation

INTRODUCTION

The global paper industry faces increasing pressure due to rising paper demand and declining wood resources caused by deforestation exceeding forest regeneration capacity. The Food and Agriculture Organization (FAO) reports that global paper and cardboard consumption has exceeded 400 million tons annually and is projected to grow by 2.1% per year until 2030 [1]. In Indonesia, this

problem is becoming increasingly critical, with high deforestation rates in hectares per year during the period 2015–2022 [2]. In Indonesia, this issue is becoming more critical, with deforestation rates ranging from 115,000–180,000 ha annually during 2015–2022 [2]. These conditions encourage the development of sustainable non-wood raw materials for pulp production. Consequently,

lignocellulosic biomass from agricultural and plantation residues has gained global attention as an alternative pulp source. Several biomasses, including rice straw (*Oryza sativa* L.), sugarcane bagasse (*Saccharum officinarum* L.), sisal fiber (*Agave sisalana*), kenaf (*Hibiscus cannabinus* L.), and bamboo fiber (*Bambusa* spp.), have demonstrated strong potential for paper production [3], [4]. Non-wood biomass generally contains lower lignin levels, requiring less energy and chemicals during delignification [5]. Among these materials, oil palm leaves represent a highly promising yet underexplored alternative biomass resource.

Indonesia is the world's largest producer and exporter of palm oil, with plantations reaching 16.38 million hectares in 2023 and crude palm oil (CPO) production reaching 50.07 million tons [6]. This massive scale of production produces not only CPO but also extraordinary quantities of waste biomass [7], [8], [9]. It is estimated that each hectare of oil palm plantation produces between 11–25 tons of dry matter biomass per year from various plant parts, including empty fruit bunches (EFB), leaf sheaths, mesocarp fiber, seed shells, and leaves [10]. Of this total biomass, oil palm leaves are the most abundant but least utilized component. Each mature oil palm tree produces an average of 20–22 fronds per year, which are routinely pruned, resulting in an estimated leaf waste of 652.08 kg/ha/month based on an average of 143 trees/ha in this study—a volume that ensures a continuous supply of raw materials.

From a chemical composition perspective, oil palm leaves contain lignocellulosic compounds consisting of cellulose, hemicellulose, and lignin as their main structural components. The cellulose content in oil palm leaves is reported to vary between 10.1–41.9% depending on the analytical method, agroclimatic conditions, plant age, and leaf part analyzed [11], [12]. Lack of utilization of leaf fiber so it does not contribute to waste reduction and resource optimization [13]. Cellulose is a long-chain glucose polymer that forms the fiber structure and provides mechanical strength to paper, making its content a key

indicator in evaluating potential pulp raw materials [14]. Hemicellulose (15–30%) acts as a binding matrix between cellulose fibers, while lignin (15–35%) functions as a structural adhesive that must be removed through a delignification process to liberate the cellulose fibers [15]. These compositional differences directly determine the efficiency of the pulping process and the final characteristics of the resulting paper.

Although several previous studies have explored the use of various oil palm wastes—particularly empty fruit bunches (EFB) and mesocarp fiber—as raw materials for pulp and paper, specific studies on oil palm leaves are still very limited in the international scientific literature [16], [17], [18], [19]. The majority of existing studies focus more on the physicochemical characterization of oil palm, rather than on systematic paper production [20]. The main problem in the current paper industry is the high dependence on wood as the primary fiber source, which results in environmental damage and limited raw material supply. On the other hand, oil palm leaf waste is available in abundant quantities but has not been optimally utilized. This raises important questions about the extent of the potential of oil palm leaves as an alternative raw material in paper production. Furthermore, scientific studies are needed to determine the characteristics of oil palm leaf fiber and its compliance with paper industry standards.

Within a broader sustainability framework, the use of oil palm leaves as a raw material for paper aligns with the principles of a circular economy, which is increasingly becoming a dominant paradigm in global industrial policy. A circular economy emphasizes the elimination of waste and pollution, the circulation of products and materials for the highest value, and the regeneration of natural systems [21]. The transformation of oil palm leaves from discarded waste to raw material for the paper industry is a concrete manifestation of these principles, while contributing to the achievement of several UN Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and

Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 15 (Ecosystems on Land) [22]. At the national level, this research is also relevant to the downstream policy of the palm oil industry, a priority of the Indonesian government, particularly in promoting the added value of palm oil derivative products beyond palm oil itself [23].

The novelty of this research lies in three fundamental aspects. First, it integrates quantitative biomass availability analysis with paper product quality evaluation within a cohesive research framework. Second, it comparatively evaluates two pulp composition formulations—100% oil palm fronds versus a 50%:50% blend with recycled pulp—and relates the differences in product characteristics to their potential market

applications. Thus, this research not only provides an empirical contribution to the literature on biomass and paper technology but also offers strategic recommendations for industry and policy stakeholders. Therefore, this study aims to quantify the potential availability of oil palm fronds as a raw material for a sustainable palm biomass-based paper industry. This study offers a solution through analyzing the potential of oil palm fronds as an alternative raw material in papermaking using a fiber characterization approach and testing the quality of the resulting pulp. With this approach, it is hoped that the technical feasibility of oil palm leaf as a paper raw material can be determined. Thus, this solution not only addresses the problem of raw materials but also supports environmental sustainability and resource efficiency.

MATERIALS AND METHODS

Research Location and Time

The research was conducted in January–February 2026 at the Agronomy Laboratory of the Yogyakarta Plantation Community Academy and the Ungaran Research and Education Plantation, Central Java, Indonesia. These locations were chosen due to the availability of a representative collection of oil palm plants and adequate laboratory facilities for testing the physical and chemical properties of the material.

Materials and Equipment

The main research materials were fresh oil palm (*Elaeis guineensis* Jacq.) leaves harvested during harvesting. The chemicals used included sodium hydroxide (NaOH) as a delignification agent, distilled water for washing and pH neutralization, and waste paper as a pulping agent. The equipment used included a knife and chopper for material preparation, a digital analytical balance (accuracy 0.01 g), an electric stove, a 1000 mL graduated cylinder, a manual paper sheet mold (frame 21 x 29.7 cm), a digital caliper, and universal pH paper.

Experimental Design

The study used a laboratory experimental design with two pulp composition treatments: Treatment P1 (100% oil palm fronds) and Treatment P2 (50% oil palm fronds + 50% recycled paper pulp). Each treatment was replicated three times. Data were analyzed descriptively and comparatively to identify differences in characteristics between treatments and product application suitability.

Research Procedure

Material preparation: Fresh oil palm leaves were cleaned of dirt with running water, separated from the rachis (leaf veins), and then cut into pieces measuring approximately 2–3 cm. **Pulping (delignification) process:** 100 g of dry material was weighed and then added to a 10% (w/v) NaOH solution with a material: solution ratio of 1:10 (w/v). The mixture was heated at 100°C for 60 minutes in an open-air bath with periodic stirring. After cooking, the pulp was washed repeatedly with distilled water until the pH was neutral (pH 6.5–7.0), then drained. **Fiber refinement:** The wet pulp was ground using a 500 W blender for 2 minutes to produce a homogeneous fiber suspension and break intramolecular hydrogen

bonds to improve interfiber bonding. Sheet formation: The fiber suspension was poured into a 21 x 29.7 cm mold fitted with a 100-mesh sieve.

After cooling at room temperature for 30 minutes, the paper was removed from the mold and stored in dry conditions for testing.

RESULTS AND DISCUSSION

Potential Availability of Oil Palm Leaf Biomass

Field observations indicate that oil palm plantations with an average population of 143 trees/ha produce an average of 2 fronds/tree/month through routine pruning. With an average leaf weight of 2.28 kg/frond, the total leaf biomass production per hectare per month can be calculated

as follows: $143 \text{ trees} \times 2 \text{ fronds} \times 2.28 \text{ kg} = 652.08 \text{ kg/ha/month}$. This value is equivalent to 7,824.96 kg/ha/year, or approximately 7.82 tons/ha/year of fresh material. This potential is significant considering that the total area of oil palm plantations in Indonesia reaches 16.38 million hectares, which could theoretically produce more than 128 million tons of leaf biomass per year nationwide.

Table 1. Potential Availability of Oil Palm Leaf Biomass per Hectare

Parameter	Values	Unit
Plant population	143	Stand/ha
Palm frond production	2	Fornd/Stand/month
Leaf weight per frond	2.28	kg/Frond
Total leaf biomass	652.08	kg/ha/month
Total leaf biomass (Year)	7,824.96	kg/ha/years
National estimate (16.38 million ha)	>128 Million	ton/years

The results of this study confirm that oil palm leaves are available in massive and sustainable quantities as a direct consequence of routine plantation maintenance practices [24]. Harvesting oil palm leaves is a routine pruning activity that is integrated into the plantation management system, thus requiring no additional costs for raw material procurement. Pruning has many benefits for plants, including improving plant health, stimulating flowering, and increasing production [25]. Unlike forest wood, which requires a 20–30-year cutting cycle, oil palm leaves are available monthly throughout the productive life of the plant (25–30 years), providing a much more consistent and predictable supply guarantee. According to Rendón-Camargo et al. [10], found that the high renewability of oil palm biomass is a fundamental competitive advantage of oil palm leaves compared to conventional wood raw materials. From an industrial logistics perspective, the guaranteed and distributed availability of raw

materials around the plantation also minimizes transportation costs and the risk of supply chain disruptions. The large potential of Indonesian oil palm leaf biomass indicates that, from a raw material availability perspective, oil palm leaves have a very significant quantity surplus to meet the needs of the paper industry.

Oil palm leaves have the potential to be comparable to bamboo and kenaf as a source of high-quality cellulose fiber, particularly after TEMPO-oxidation treatment to produce cellulose nanofiber (CNF). According to Abdul Rahim et al. [26], the oil palm biomass is a promising candidate for sustainable applications. According to Syukri et al. [18] and Tan et al. [17] found that with proper process optimization, oil palm pulp can meet minimum specifications for certain paper applications. This is consistent with the findings of this study, which showed that a 50:50 blend produces paper with better mechanical strength

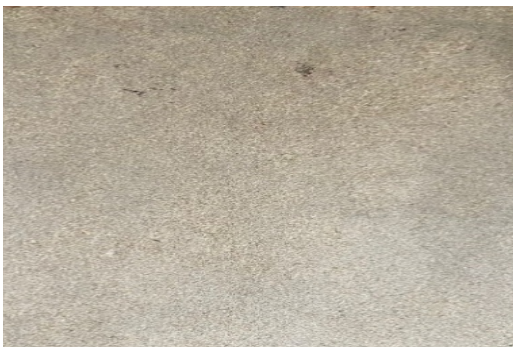
than the pure formulation. Furthermore, Kahar et al. [5] found that revenue from co-byproducts can reach 40–60% of total biorefinery revenue, making oil palm leaf-based paper production more economically competitive than a single-product scenario. This biorefinery concept represents a logical evolution of oil palm leaf utilization from the laboratory scale to sustainable industrialization. Oil palm leaves not only have the potential as a raw material for conventional paper, but also as a source of high-value cellulose nanomaterials for biocomposite applications, packaging biofilms, and functional materials.

Rendemen Pulp Paper Quality

The delignification process with NaOH produces pulp yields ranging from 42–58% of the dry weight of the initial raw material. Yield variations are influenced by raw material heterogeneity (leaf age, storage conditions) and the efficiency of the washing process. Table 2 and Figure 1 present a comparison of the characteristics of the paper produced from the two composition treatments.

Table 2. Characteristics of Paper Produced from Two Variations of Material Composition

Parameter	P1: 100% Palm Leaves	P2: 50% Palm Oil + 50% Recycled Pulp
Colour	Natural yellowish brown	Brighter/white
Surface Texture	Coarse, fibers clearly visible	Smoother and more homogeneous
Potential Applications	Art paper, crafts, artisanal packaging	Eco-friendly packaging



a



b

Fig 1. a. P1: 100% Palm Leaves, b. P2: 50% Palm Oil + 50% Recycled Pulp

The significant differences in paper characteristics between P1 (100% palm fronds) and P2 (50% palm fronds + 50% recycled pulp) reveal a synergistic effect of the material blending that directly affects the physical and mechanical properties of the final product. P1 paper exhibits a rough texture with visually visible fibers, a natural yellowish-brown color, a higher grammage, and a greater thickness. These characteristics are in line with Adeoye et al. [27], non-wood biomass-based paper generally has a rougher surface and a darker color than conventional wood paper due to the remaining lignin and extractive residues. In

contrast, the P2 paper exhibits better homogeneity, a smoother surface, and superior mechanical strength. This finding has important practical implications, blend formulations can be tuned to achieve a wide spectrum of product characteristics, from artisanal art paper to functional packaging paper, without fundamentally changing the production process.

From a more technical product quality perspective, P1 paper with a grammage of 80–95 g/m² and a natural rough texture positions itself in the premium artisanal and art paper segment. This

market segment is experiencing significant global growth, driven by increasing consumer preferences for handmade and environmentally friendly products. Rajesh et al. [28] found that agricultural biomass-based paper can provide a viable alternative for industries producing handmade

CONCLUSION

Oil palm leaves (*Elaeis guineensis* Jacq.) have significant potential as an alternative raw material in the sustainable paper industry. The abundant and continuous availability of biomass, reaching 7.82 tons/ha/year of fresh material, provides a strategic advantage over conventional wood sources that require long regeneration times. Variations in raw material formulations result in different product characteristics, thus opening up opportunities for market diversification, ranging from high-value art paper to environmentally friendly packaging. Furthermore, the use of oil

paper. P2 paper with characteristics closer to standard packaging paper opens up greater market opportunities, particularly in the rapidly growing eco-friendly food packaging and e-commerce packaging segments.

palm leaves contributes to the reduction of biomass waste, potential greenhouse gas emissions, and reduced pressure on forest resources, in line with the principles of a circular economy and the Sustainable Development Goals (SDGs). From an economic perspective, the use of oil palm leaf waste as a cheap and locally available raw material has the potential to increase the added value of the plantation industry and encourage biomass-based economic development in oil palm growing regions.

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