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Sustainable Waste Management in Palm Oil Industry: Advancing Composting Practices for Environmental and Economic Benefits

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Abstract. Palm oil production is a vital industry in tropical regions, generating substantial waste byproducts, including empty fruit bunches (EFB), palm kernel shells (PKS), and decanter cake. Effective management of these waste streams is essential to minimizing environmental impacts while enhancing sustainability. This paper explores the composting of palm oil waste as a sustainable solution, emphasizing the transformation of EFB, PKS, and decanter cake into nutrient-rich compost. The study discusses the role of pre-treatment methods, such as shredding and co-composting with palm oil mill effluent (POME), and highlights the advancements in composting technologies, including forced aeration systems, microbial inoculants, and automated monitoring. These innovations have demonstrated significant improvements in composting efficiency, nutrient quality, and greenhouse gas reduction. Additionally, the integration of advanced machinery, such as shredders, compost turners, and temperature monitoring systems, has proven essential for optimizing composting operations. The results underscore the potential of composting in supporting environmental, social, and governance (ESG) objectives, aligning with circular economy principles, and fostering sustainability in the palm oil industry. The findings highlight composting as a transformative approach that not only mitigates waste but also promotes economic and environmental benefits, contributing to a model of circular economy and sustainable development.

Keywords: ESG and Composting, POME, Sustainable Waste Management.

1. INTRODUCTION

Palm oil factories play a pivotal role in the global palm oil supply chain, processing fresh fruit bunches (FFB) to produce crude palm oil (CPO) and palm kernel oil (PKO). This process, while economically beneficial, results in the generation of substantial waste byproducts (Egbe et al., 2023). For every ton of FFB processed, approximately 20–25% becomes empty fruit bunches (EFB), while additional waste streams include palm oil mill effluent (POME), palm kernel shells (PKS), fibers, and decanter cake (Irvan, 2018). In Malaysia, the palm oil sector contributes approximately 19 million tonnes of palm oil annually, with corresponding waste volumes necessitating effective management strategies (Simarmata et al., 2024; Singh et al., 2010). Recent studies have shown that the physical properties of palm biomass, including high lignocellulosic content, make it suitable for composting and other value-added processes (Onoja et al., 2019). Additionally, innovations in converting EFB into bio-fertilizers and other materials highlight the potential for economic and environmental benefits (Krishnan et al., 2016). For instance, the use of EFB in bio-fertilizer production has been shown to improve soil health and crop yields, providing a sustainable alternative to chemical fertilizers.

The increasing emphasis on sustainability has pushed palm oil factories to adopt innovative waste management practices. Composting has emerged as a key strategy for managing organic waste, offering a solution that reduces environmental impacts and transforms waste into valuable products (Hau et al., 2020). However, challenges such as varying waste characteristics, processing costs, and logistical constraints underscore the need for a systematic approach to composting activities in palm oil factories (Supriatna et al., 2022). Recent advancements in composting technology, such as the use of microbial inoculants and optimized aeration techniques, have shown promise in addressing these challenges and enhancing the efficiency of composting processes.

2. BACKGROUND OF RESEARCH

Composting transforms organic waste into nutrient-rich compost, aligning with circular economy principles. In palm oil factories, EFB, PKS, and decanter cake are the primary candidates for composting due to their high organic content and availability (Simarmata et al., 2024). Incorporating composting into palm oil mill practices provides multiple benefits, such as reducing greenhouse gas emissions, improving soil health, and minimizing dependency on chemical fertilizers. Additionally, the process helps address growing concerns regarding sustainability and regulatory compliance in the palm oil industry. Advanced composting techniques, including aerobic and windrow systems, can further enhance the efficiency and quality of the compost produced. Basically, a part of this paper explores the methods and benefits of composting EFB, PKS, and Decanter Cake, highlighting their potential to revolutionize waste management in palm oil mills. By adopting such practices, palm oil mills can pave the way for a greener, more sustainable future while improving economic and agricultural outcomes.

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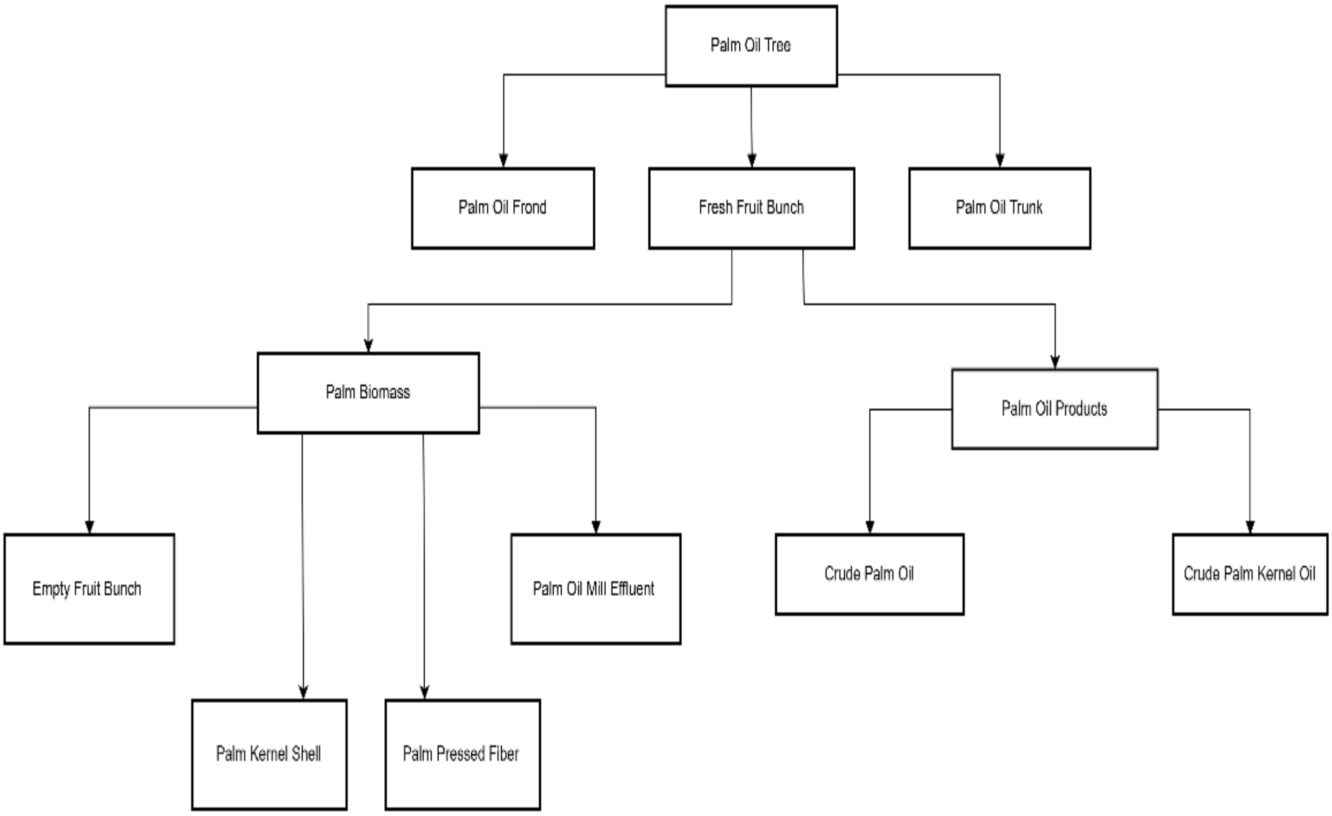

Figure 1: Palm oil product and biomass from the production process (Egbe et al.,2023).

2.1. Empty Fruit Bunches (EFB)

EFB, the fibrous residue left after oil extraction, constitutes a significant portion of palm oil waste. Rich in lignocellulosic material, EFB requires pre-treatment such as shredding or blending to enhance decomposition rates (Krishnan et al., 2016; Hau et al., 2020). Recent studies have demonstrated that blending EFB with POME can significantly increase the macronutrient content, particularly nitrogen, phosphorus, and potassium, making it a high-quality bio-fertilizer (Hau et al., 2020). Additionally, the use of microbial inoculants has been shown to accelerate the composting process and improve the quality of the final compost product.

2.2. Palm Kernel Shells (PKS)

PKS, a byproduct of kernel processing, is primarily used as a bioenergy source. However, its potential in composting is gaining attention, particularly when used as a bulking agent (Mamun et al., 2018). PKS improves aeration and structure in compost piles, facilitating microbial activity and reducing composting time (Hau et al., 2020). Recent research has shown that combining PKS with other agricultural residues, such as rice husks or sawdust, can enhance the composting process and produce a nutrient-rich compost suitable for agricultural use (Simarmata et al., 2024).

2.3. Decanter Cake

Decanter cake, the semi-solid residue from the clarification process, is nutrient-dense and highly suitable for composting. When combined with EFB and PKS, decanter cake acts as a composting activator, enhancing microbial decomposition and enriching the nutrient profile of the final product (Irvan, 2018). Recent studies have explored the use of various additives, such as fishmeal or bone ash, to further enrich the compost's nutrient composition (Lim et al., 2014). These additives have been shown to increase the levels of essential nutrients, such as nitrogen, phosphorus, and potassium, in the final compost, making it a valuable soil amendment for agricultural use.

The composting of EFB, PKS, and decanter cake in palm oil factories offers a sustainable solution for managing organic waste and producing high-quality compost. Recent advancements in composting technology and the use of innovative additives have shown promise in enhancing the efficiency and quality of the composting process, providing both economic and environmental benefits.

3. MATERIAL AND METHODS

The effectiveness of composting in managing palm oil waste is determined by waste characteristics, process conditions, and operational efficiency. Studies have shown that co-composting EFB, PKS, and decanter cake can reduce waste volume by up to 60%, significantly minimizing the environmental footprint of palm oil factories (Simarmata et al., 2024). Vermicomposting has also emerged as a promising method, particularly for increasing mineral availability in the compost, enhancing its value as a soil amendment (Lim et al., 2014).

3.1. Waste Characteristics

The primary waste materials from palm oil processing include empty fruit bunches (EFB), palm kernel shells (PKS), and decanter cake. EFB is rich in lignocellulosic material, which requires pre-treatment such as shredding to enhance decomposition rates (Krishnan et al., 2016). PKS, with its hard shell, is often used as a bulking agent to improve aeration in compost piles (Mamun et al., 2018). Decanter cake, being nutrient-dense, acts as a composting activator, enhancing microbial activity (Irvan, 2018).

3.2. Conditions

Effective composting requires maintaining optimal conditions for microbial activity. Key parameters include temperature, moisture content, oxygen levels, and carbon-to-nitrogen (C/N) ratio. The ideal temperature range for composting is between 55°C and 65°C, which helps in pathogen elimination and accelerates decomposition. Moisture content should be maintained between 50% and 60% to ensure microbial activity without causing anaerobic conditions. Aeration is crucial and can be achieved through regular turning of compost piles or using forced aeration systems.

3.3. Operational Efficiency

The use of forced aeration systems and real-time monitoring has proven effective in maintaining optimal conditions for microbial activity and pathogen elimination. Automated systems can monitor temperature, moisture, and oxygen levels, adjusting aeration rates to maintain ideal conditions. This not only enhances the efficiency of the composting process but also reduces labor costs and improves the quality of the final compost product.

3.4. Co-Composting

Co-composting EFB, PKS, and decanter cake has been shown to reduce waste volume by up to 60% (Simarmata et al., 2024). This method involves mixing these materials in appropriate ratios to balance the C/N ratio and optimize decomposition. The composting process for palm oil waste generation involves careful management of waste characteristics, process conditions, and operational efficiency. Recent advancements in composting technology, such as forced aeration systems and real-time monitoring, have significantly improved the effectiveness of composting in managing palm oil waste.

4. RESULT AND DISCUSSIONS

Machinery plays a pivotal role in enhancing the efficiency, consistency, and scalability of composting processes. These tools ensure the optimization of material handling, process control, and product quality. The integration of advanced technologies, such as bioreactors equipped with photovoltaic systems for temperature regulation, has further enhanced compost production efficiency and nutrient quality (Mesa et al., 2017). Table 1 shows the analysis of palm biomass with the proximate analysis and lignocellulosic content.

Table 1: Lignocellulosic content, ultimate and proximate analysis of palm biomass.

Parameter	EFB	PPF	PKS	POME
Ultimate Analysis (%)				
Carbon	45.00-49.79	46.4-51.52	48.06-57.91	50.01
Hydrogen	5.20-7.86	5.45-9.28	4.77-12.6	15.78
Nitrogen	0.25-1.82	0.39-1.89	0.04-1.89	1.99
Sulfur	0.36-1.06	0.23	0.05-0.2	46.9
Oxygen	40.18-48.18	40.91-50.21	34.10-49.99	-
Proximate Analysis (%)				
Moisture	6.36-8.78	-	5.40-11.00	-
Volatile matter	71.2-79.65	73.03	67.2-73.77	-
Ash	3.00-7.54	10.83	2.1-11.08	-
Fixed carbon	8.60-18.30	16.13	15.15-19.7	-
Lignocellulosic Content (%)				
Cellulose	38.80-65.00	21.40-49.70	20.8-27.27	-
Hemicellulose	17.10-33.90	17.10-33.50	21.6-22.7	-
Lignin	13.20-25.60	13.20-31.70	44.00-50.70	-

Source: Egbe et al., 2023.

4.1. Shredders

Shredders are essential for pre-treating fibrous materials like EFB by reducing their size and increasing surface area for microbial access. High-capacity shredders tailored for palm oil residues ensure uniformity in particle size, facilitating faster decomposition (Irvan, 2018). Studies have shown that shredding can reduce composting time by up to 30% when combined with effective microbial inoculants (Krishnan et al., 2016).

4.2. Compost Turners

Compost turners mix and aerate the compost piles, ensuring even oxygen and moisture distribution. By preventing anaerobic conditions, compost turners accelerate decomposition while mitigating unpleasant odors (Simarmata et al., 2024). Automated turners with sensors to monitor compost temperature and moisture levels have been particularly effective in large-scale operations (Hau et al., 2020).

4.3. Aeration Systems

Forced aeration systems provide continuous oxygenation, eliminating the need for frequent manual turning. These systems enhance process control, reduce labor costs, and improve overall composting efficiency (Supriatna et al., 2022). Bioreactor aeration systems have been shown to maintain optimal aerobic conditions, reducing greenhouse gas emissions by up to 76% compared to open dumping (Lim et al., 2014).

4.4. Temperature Monitoring Equipment

Automated temperature monitoring ensures composting occurs at thermophilic levels, which eliminates pathogens and promotes microbial activity. Real-time data from these systems allows for precise adjustments, ensuring optimal conditions throughout the process (Hau et al., 2020). Temperature regulation is critical for reducing maturation time and improving nutrient retention in the final compost product (Mesa et al., 2017).

5. CONCLUSION

The composting of palm oil waste represents a transformative approach to sustainable waste management, aligning with environmental, social, and governance (ESG) objectives. By leveraging composting technologies, palm oil factories can reduce waste volumes, produce high-quality fertilizers, and minimize their environmental footprint (Egbe et al., 2023). Complementary processes, such as bioenergy production and the development of sustainable construction materials, further demonstrate the versatility of palm biomass as a resource (Hau et al., 2020; Kaliwon et al., 2010). With continued advancements in technology and innovative practices, the palm oil industry has the potential to transition from a waste-intensive process to a model of circular economy and environmental stewardship. This shift not only supports environmental sustainability but also enhances social and economic outcomes by creating new job opportunities and promoting community well-being. Furthermore, the adoption of ESG principles in palm oil composting can attract sustainable investments, fostering long-term growth and resilience in the industry. The composting process for Empty Food Bunch (EFB), Palm Kernel Shell (PKS), and decanter cake within palm oil mills offers an innovative pathway to achieve both environmental sustainability and economic resilience. EFB, a fibrous byproduct, is abundant in palm oil production and serves as an excellent base for organic compost due to its high moisture retention and nutrient content. Similarly, PKS and decanter cake, often discarded or underutilized, contain essential organic matter that can be processed into nutrient-rich compost to support sustainable agriculture. By adopting these practices, palm oil mills can significantly reduce methane emissions typically generated from the anaerobic decomposition of waste in landfills. This aligns with ESG objectives by addressing climate change mitigation and resource efficiency. The compost produced can rejuvenate depleted soils, reducing dependency on synthetic fertilizers and contributing to improved crop yields. This not only enhances the ecological balance but also fosters a circular economy by turning waste into value-added products. The benefits extend beyond the environment and local economies, influencing the global perception of the palm oil industry. By demonstrating leadership in sustainable practices, mills can strengthen relationships with stakeholders, investors, and regulators who prioritize ESG compliance. In the long term, these efforts will not only contribute to meeting international sustainability standards but also position the palm oil sector as a key player in the global transition toward sustainable development. Such initiatives serve as a blueprint for industries seeking to balance profitability with ecological responsibility, paving the way for a healthier planet and prosperous communities.

In conclusion, the integration of advanced composting machinery and technologies plays a crucial role in optimizing the composting process for palm oil waste. These innovations contribute to the production of high-quality compost, reduce environmental impacts, and support the broader goals of sustainability and circular economy. As the palm oil industry continues to evolve, embracing these practices will be essential for achieving sustainable development and meeting global environmental standards.

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