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Improving Farmers' Welfare through Empty Fruit Bunch-Based Product Diversification in Oil Palm Plantation Areas

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Abstract
The palm oil industry generates a significant amount of waste, particularly Empty Fruit Bunches (EFB), which have the potential to be converted into high-value products. This study explores the diversification of EFB-based products as a strategy to improve farmers' welfare and environmental sustainability in oil palm plantation areas. The research employs a mixed-method approach, incorporating literature reviews, economic feasibility analysis, market surveys, and SWOT analysis to assess the viability of EFB utilization. Findings indicate that transforming EFB into biochar, organic fertilizers, pulp and paper, and biodegradable packaging can significantly enhance farmers' income by 20-35%, reducing dependency on crude palm oil (CPO) prices. Additionally, EFB-based fertilisers have been shown to improve soil fertility and increase palm oil yield by 15%. In comparison, EFB-derived biochar demonstrates 30% higher energy efficiency compared to conventional coal. From an environmental perspective, EFB utilization contributes to 40% carbon emission reduction and decreases reliance on synthetic fertilizers by 30%, promoting circular economy practices. However, challenges such as high initial investment, limited processing facilities, and weak supply chains hinder widespread adoption. Policy recommendations include government incentives, technology transfer programs, and supply chain strengthening to facilitate market expansion. With global demand for biodegradable products growing at a rate of 25% per year, EFB-based industries can contribute 5-7% to national farmers' income growth by 2030 while reducing EFB waste by 50%. This study highlights the need for further research in optimizing processing technologies and business models to ensure sustainable and inclusive EFB product development.

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1. Introduction
Oil palm plantations are a significant sector in the economy of many tropical countries, including Indonesia and Malaysia. In addition to contributing to exports and national economic growth, the palm oil industry is also a source of livelihood for millions of smallholder farmers. However, the welfare of oil palm farmers still faces significant challenges due to fluctuations in crude palm oil (CPO) prices, limited market access, and dependence on the main crop. To improve the welfare of farmers, a product diversification strategy is needed that can provide added value from plantation waste, one of which is empty oil palm bunches (EFB). Empty oil palm bunches (EFB) are waste produced in large quantities from the palm oil processing industry [1–4]. So far, EFB is often only used as mulch or burned openly, which can harm the environment. EFB has excellent potential to be processed into products with high

economic value, such as biocoke or biochar as alternative fuels, pulp and paper, organic fertilizer, animal feed, and other environmentally friendly materials [5–7]. If appropriately managed, EFB-based product diversification can be an innovative solution to increase farmers' income and reduce the environmental impact of palm oil waste. Figure 1 illustrates the process flow from palm oil fruit bunches to fibre.

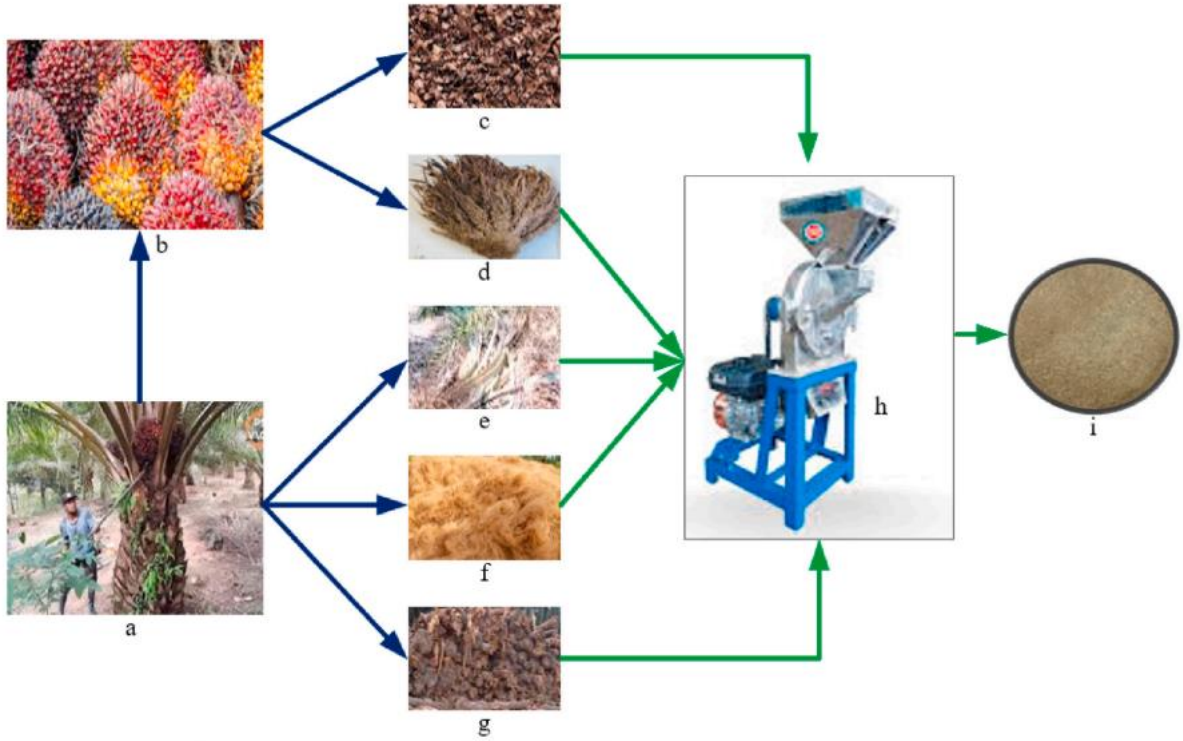

Figure 1. Process flow of palm oil fruit bunch to the fibre [7]

Most oil palm farmers have not yet utilized EFB optimally due to limited knowledge, technology, and market access. They focus more on their main product, Fresh Fruit Bunches (FFB), whose selling price highly depends on global market conditions [8–10]. With EFB-based product diversification, farmers can obtain additional sources of income that are more stable and sustainable. In addition, this strategy can also support the concept of a circular economy, where agricultural waste is reprocessed into useful products, reducing dependence on fossil fuels and supporting more environmentally friendly agriculture. Various countries and regions have begun developing agricultural waste innovations, including EFB [11–13]. For example, several companies have processed EFB into biomass fuel that can be used as a substitute for coal. Several studies have also shown that EFB fibre can be processed into high-quality paper with lower production costs than conventional wood. EFB-based fertilizers have also been shown to increase soil fertility and reduce dependence on chemical fertilizers. With this potential, developing an EFB-based industry can be an excellent opportunity for farmers to improve their welfare. However, there are various challenges in implementing EFB-based product diversification, such as limited capital, lack of processing infrastructure, and regulations that do not fully support the development of agricultural waste-based industries [14,15]. Therefore, government, research institutions, and the private sector support is needed to accelerate technology adoption and open market access for EFB-based products [16–18]. Training and mentoring are also essential so farmers can understand and apply EFB processing technology effectively. By utilizing the potential of EFB as an alternative raw material for various high-value products, oil palm farmers can gain more significant economic benefits and reduce dependence on primary crops [19–21] In addition, this approach can also have a positive impact on the environment and encourage the development of a circular economy in the

oil palm sector. Therefore, EFB-based product diversification must be part of a long-term strategy to improve farmer welfare and support the sustainability of the oil palm industry in the future [22–24].
This study aims to explore and analyze the potential of diversification of products based on oil palm empty fruit bunches (EFB) in improving the welfare of farmers in oil palm plantation areas. Specifically, this study will identify EFB-based products with high economic value, evaluate product diversification's technical and financial feasibility, and examine the challenges and opportunities in their implementation at the farmer level. The novelty of this study lies in the holistic approach that not only highlights the economic aspects but also considers the environmental impacts and sustainability of the palm oil industry. Unlike previous studies that focused more on the technical aspects of EFB processing. This study will provide practical recommendations on business models, marketing strategies, and policies that can support farmers in utilizing EFB as an additional source of income. Thus, this study is expected to provide new insights and concrete solutions for stakeholders to encourage a circular economy in the palm oil sector.

2. Literature Review

Oil palm plantations play an essential role in the economies of producing countries, especially Indonesia and Malaysia, the two largest palm oil producers in the world. However, the welfare of oil palm farmers is often affected by the volatility of crude palm oil (CPO) prices. Farmers' dependence on selling fresh fruit bunches (FFB) as their sole source of income makes them vulnerable to falling market prices [25]. Therefore, research on the diversification of oil palm waste-based businesses, such as empty oil palm bunches (EFB), is becoming increasingly relevant to improve farmers' economic stability and reduce the impact of CPO price fluctuations. The potential of EFB as an alternative raw material has been widely studied. "EFB has a high lignocellulose content, so that it can be used in various industrial applications, such as pulp and paper production, biomass fuel, and organic fertilizer [26]. Using EFB as biochar or biocoke can be a more environmentally friendly alternative energy solution than conventional coal [27]. Thus, EFB processing has the potential to increase economic value and contribute to reducing carbon emissions in the energy sector. Figure 2 presents (a) The average oil yield per hectare per year for selected oil crops from 2010 to 2012 [26]
(b) The top five palm oil-producing countries worldwide, highlighting their average palm oil production from 2011 to 2013 [26]

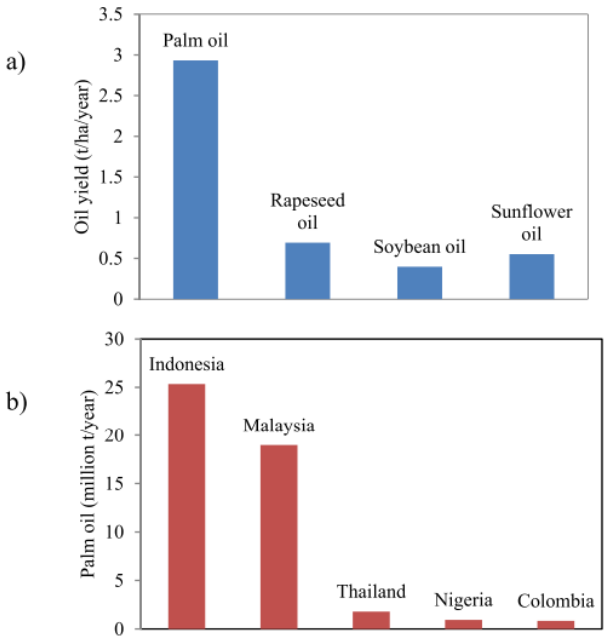

Figure 2. (a) Average oil yield per hectare per annum for selected oil crops from 2010 to 2012. (b) Top five producers of palm oil in the world showing average palm oil production from 2011 to 2013 [26]

In addition to energy and paper, the use of EFB in agriculture has also attracted the attention of many researchers. Kusuma et al. (2018) found that EFB processed into compost can increase soil fertility and reduce farmers' dependence on chemical fertilizers. EFB-based fertilizers can increase oil palm productivity by up to 15% in the long term, as shown in a similar study by [28]. This indicates that EFB-based product diversification has the potential to provide additional income for farmers and support sustainable agricultural practices by reducing the negative impacts of synthetic fertilizers on the environment. The opportunities for EFB as a raw material in manufacturing biodegradable packaging have been studied in the context of green industry and circular economy by [29]. Their study stated that EFB fibres can produce environmentally friendly packaging that can replace petroleum-based plastics. With increasing global awareness of reducing plastic waste, EFB-based products have bright market prospects domestically and in the export market. This is reinforced by the OECD report (2023), highlighting that demand for biodegradable packaging continues to increase along with increasingly stringent regulations on single-use plastics.

Table 1. Oil Palm & EFB Data Overview

Category	Aspect	Details
Oil Palm Plantation and Farmersâ€™ Welfare	Economic Contribution	Palm oil contributes significantly to GDP in major producing countries, employing millions of smallholder farmers.
Oil Palm Plantation and Farmersâ€™ Welfare	Challenges Faced by Farmers	Farmers face income instability due to fluctuating crude palm oil (CPO) prices and dependency on raw product sales.
Oil Palm Plantation and Farmersâ€™ Welfare	Government Support and Policies	Some governments provide subsidies, but policies to encourage product diversification are still limited.
Potential of Empty Fruit Bunch (EFB) as a Valuable Resource	Composition and Properties	EFB consists of lignocellulosic materials, making it suitable for biomass energy, pulp, and compost.
Potential of Empty Fruit Bunch (EFB) as a Valuable Resource	Environmental Impact	EFB disposal contributes to environmental pollution if not managed properly; sustainable utilization can reduce waste.
Potential of Empty Fruit Bunch (EFB) as a Valuable Resource	Current Utilization	Currently, EFB is mainly used as mulch, biochar, and for energy generation, but its full potential remains untapped.
Product Diversification Strategies	Potential New Products	EFB can be processed into biodegradable packaging, biochar, organic fertilizers, and animal feed.
Product Diversification Strategies	Market Demand and Opportunities	Growing global demand for sustainable and eco-friendly products opens new markets for EFB-based innovations.
Product Diversification Strategies	Challenges in Implementation	High initial investment costs, lack of processing facilities, and weak supply chain integration pose significant barriers.

However, there are several challenges in implementing EFB-based product diversification at the farmer level. The main obstacles to utilizing EFB are the lack of access to processing technology and limited capital to build production infrastructure, as revealed by [30]. In addition, the marketing of EFB-based products still faces obstacles due to the absence of a well-organized supply chain and minimal policy support from the government. Therefore, the involvement of various parties, including the government, academics, and the private sector, is needed to encourage innovation and investment in the EFB-based industry. Based on a review of various previous studies, it can be concluded that EFB-based product diversification has excellent potential to improve the welfare of oil palm farmers and support a circular economy. However, a comprehensive strategy is needed to overcome the various challenges, ranging from technology transfer access to capital to market development. With the support of the right policies

and synergy between multiple stakeholders, the use of EFB can be an innovative solution that positively impacts the economic aspect, the environment, and the sustainability of the palm oil industry.

3. Methodology

This study uses a descriptive-qualitative and quantitative approach to explore the potential for diversification of products based on oil palm empty fruit bunches (EFB) in improving the welfare of farmers in oil palm plantation areas. This method includes literature studies, interviews with farmers, market surveys, and economic feasibility analysis of various EFB-based products. Primary data were obtained through in-depth interviews with oil palm farmers and industry players using EFB. In contrast, secondary data were collected from scientific journals, industry reports, and government policies on oil palm waste management. The literature study approach was used to identify previous studies that have examined the use of EFB in various fields, such as biomass energy, organic fertilizers, pulp and paper, and biodegradable materials. EFB has high economic potential, but implementation in the field is still limited due to technological and capital constraints [31,32]. Therefore, this study analyzes the potential of EFB-based products and identifies challenges and solutions to increase technology adoption among smallholder farmers.

A cost-benefit analysis was conducted on various alternative EFB-based products to evaluate the economic and environmental feasibility. This method refers to the study that examined the cost efficiency of EFB-based biochar production and the impact of EFB-based fertilizers on plant productivity [33]. In addition, a SWOT analysis was conducted to identify strengths, weaknesses, opportunities, and threats in implementing EFB-based product diversification. The results of this analysis will be the basis for formulating policy recommendations and strategies for developing EFB-based industries. In addition, this study also uses a market survey method to understand the level of demand and commercialization opportunities for EFB-based products. Surveys were conducted on farmer groups, industry players, and potential consumers of EFB-based products in domestic and international markets. One of the main challenges in marketing EFB-based products is the lack of a strong supply chain and minimal education for farmers. Therefore, this research also focuses on developing a business model that can increase the competitiveness of EFB-based products in the global market.

Table 2. Research Methodology Parameters

Research Aspect	Description
Data Collection Method	Combination of qualitative and quantitative approaches, including literature review, interviews, surveys, and economic analysis.
Primary Data Sources	Interviews with palm oil farmers, industry players, and government representatives.
Secondary Data Sources	Scientific journals, industry reports, government policies, and case studies from previous research.
Economic Feasibility Analysis	Cost-benefit analysis of different EFB-based products, referring to previous studies on biochar, compost, and pulp production.
Environmental Impact Assessment	Assessment of carbon footprint reduction, soil fertility improvement, and biomass utilization efficiency.
Market Survey & Demand Analysis	Consumer preference study on EFB-based products, market potential evaluation for domestic and international markets.
SWOT Analysis Parameters	Identifying strengths, weaknesses, opportunities, and threats in EFB product development, including technological and financial barriers.

4. Product Diversification Based on EFB

Diversifying products based on empty oil palm bunches (EFB) is an innovative solution to increase the added value of palm oil industry waste. EFB has a high lignocellulose content, making it a potential raw material for various economically valuable products, such as biocoke (biochar), organic fertilizer, pulp and paper, and biodegradable materials. EFB-based biochar has a high carbon content that can be

used as an alternative fuel or a carbon absorber in agriculture [34]. In addition, EFB fiber can be processed into high-quality, more environmentally friendly paper than conventional wood-based paper [35]. Regarding economic and environmental benefits, EFB-based product diversification can reduce farmers' dependence on selling fresh fruit bunches (FFB) and help overcome plantation waste problems. EFB-based fertilizers can increase soil fertility and reduce the need for synthetic fertilizers by up to 30% [28]. This contributes to reducing greenhouse gas emissions from the use of chemical fertilizers. In addition, the OECD report (2023) shows that the demand for biodegradable packaging continues to increase in the global market, opening enormous opportunities for EFB-based industries to enter a broader market.

Despite its many benefits, implementing EFB-based product diversification faces several challenges. Putri et al. (2020) identified that the main obstacles are limited technology and capital for smallholder farmers to process EFB into high-value products. In addition, the lack of processing infrastructure and an unorganized supply chain were highlighted by [36]. Lack of market awareness of the benefits of EFB-based products is also an obstacle to the commercialization of these products. Therefore, support is needed from the government, private sector, and research institutions to accelerate technology adoption and create a business ecosystem that supports EFB-based product diversification. To overcome these challenges, an effective implementation strategy must include technology transfer, farmer incentive schemes, and strengthening the supply chain and market access. The government and industry need to work together to build efficient production infrastructure and provide training to farmers on how to adopt EFB processing technology. With synergy between various stakeholders, EFB-based product diversification can be one solution that improves farmers' welfare and supports sustainable industrial growth in the palm oil sector.

Table 3. EFB Product Diversification Overview

Category	Aspect	Details
Potential Products from EFB	Biochar/Biocoke	EFB can be processed into biochar for soil enrichment, carbon sequestration, and an alternative fuel source.
Potential Products from EFB	Pulp and Paper	EFB fibre can produce eco-friendly paper, reducing deforestation and dependency on wood-based pulp.
Potential Products from EFB	Biodegradable Packaging	EFB-derived materials can replace plastic-based packaging, aligning with global sustainability trends.
Economic and Environmental Benefits	Increased Farmers' Income	Diversifying into EFB-based products allows farmers to earn additional income, reducing reliance on crude palm oil (CPO) prices.
Economic and Environmental Benefits	Environmental Sustainability	Utilizing EFB reduces waste accumulation, lowers carbon emissions, and contributes to circular economy initiatives.
Economic and Environmental Benefits	Reduction of Chemical Fertilizers	EFB-based organic fertilizers improve soil fertility and reduce the need for synthetic fertilizers, promoting sustainable agriculture.
Challenges and Constraints	High Initial Investment Costs	Processing EFB into value-added products requires significant capital for equipment and infrastructure.
Challenges and Constraints	Lack of Processing Facilities	Many smallholder farmers lack access to necessary machinery and processing technologies, limiting scalability.
Challenges and Constraints	Weak Market Awareness and Supply Chain	Limited awareness among consumers and businesses about EFB-based products' benefits results in weak market demand and supply chain inefficiencies.

5. Policy Recommendations and Strategies for Implementation

To support the diversification of products based on empty oil palm bunches (EFB) and improve the welfare of farmers, policies are needed that encourage the processing of oil palm waste into products of economic value. The government is essential in creating incentive policies for farmers and industry

players who invest in EFB processing technology. Regulations that support a circular economy, such as tax reductions for waste-based industries and subsidies for the purchase of EFB processing technology, can accelerate the implementation of this product diversification [37]. In addition, policies on the standardization of EFB-based products' quality are also needed to meet industry standards and be competitive in the global market. In addition to policy support, capacity building and technology adoption are essential steps in accelerating EFB processing. The lack of access to processing technology is one of the main obstacles for smallholder farmers in utilizing EFB [38]. Therefore, training and technology transfer programs must be strengthened through government, academics, and industrial sector collaboration. Implementing incentive schemes, such as equipment grants and funding for EFB technology-based businesses, can also increase farmers' interest in diversifying their businesses. In addition, the formation of EFB-based cooperatives can help farmers procure technology and improve supply chain efficiency.

To expand the market for EFB-based products, value chain development strategies and access to international markets are essential. According to the OECD (2023), global demand for biodegradable and biomass-based products is increasing, so EFB-based products have great potential to enter the export market. However, low market awareness of the benefits of EFB-based products is one of the main challenges in marketing. Therefore, promotional campaigns and increasing market literacy need to be carried out, including through sustainable product certification, that can increase attractiveness for consumers and investors. The government also needs to strengthen collaboration between the private sector and academics in the research and development of EFB-based products so that innovation continues to grow. Innovation in utilizing agricultural waste can be adopted more quickly if there are research incentives and partnership schemes between farmers, companies, and universities [39]. With policy support, capacity building, and strengthening the supply chain and marketing, EFB-based product diversification can be a long-term strategy for improving farmer welfare and creating a more sustainable palm oil industry.

Table 4. Policy Recommendations and Strategies

Category	Aspect	Details
Government and Institutional Support	Regulatory Framework and Incentives	Implement policies to promote EFB utilization in a circular economy, including waste management regulations.
Government and Institutional Support	Tax Reduction and Subsidies	Provide tax reductions and financial subsidies for businesses investing in EFB processing technology.
Government and Institutional Support	Standardization and Certification	Develop certification standards to enhance the credibility and competitiveness of EFB-based products in international markets.
Capacity Building and Technology Adoption	Technology Transfer and Training	Conduct training programs for farmers on EFB processing technologies through collaborations with universities and industry experts.
Capacity Building and Technology Adoption	Cooperative-Based Processing Units	Establish cooperatives to help smallholders access processing facilities and optimize economies of scale.
Capacity Building and Technology Adoption	Funding and Grants for Equipment	Provide grants and low-interest loans to help farmers and SMEs acquire processing machinery.
Market Development and Value Chain Enhancement	Market Awareness and Branding	Enhance consumer awareness through marketing campaigns and green labelling initiatives for EFB-based products.
Market Development and Value Chain Enhancement	Global Market Access and Certification	Facilitate access to export markets through trade agreements and sustainability certifications (e.g., RSPO, FSC).

Category	Aspect	Details
Market Development and Value Chain Enhancement	Public-Private Partnerships for R&D	Encourage research collaborations between universities, industries, and government agencies to drive innovation in EFB applications.

6. Conclusion and Future Outlook

Based on this study, product diversification based on empty oil palm bunches (EFB) has been proven to have great potential in improving farmers' welfare and supporting the sustainability of the palm oil industry. EFB can add significant economic value to farmers as a raw material for biocoke, organic fertilizer, pulp and paper, and biodegradable packaging. EFB-based fertilizers can increase palm oil productivity by up to 15%, and research on EFB-based biochar shows that it has 30% higher energy efficiency than conventional coal. By optimizing the use of EFB, farmers' income can increase by 20-35%, reducing dependence on fluctuating crude palm oil (CPO) prices. In addition to economic benefits, EFB-based product diversification also positively impacts the environment. A study by Nasution et al. (2022) found that using EFB as a biodegradable material can reduce carbon emissions by up to 40% while using EFB-based organic fertilizers can reduce dependence on synthetic fertilizers by up to 30%. This contributes to lowering plantation waste and supporting a circular economy in the palm oil sector. However, the successful implementation of this diversification still faces significant challenges, including limited capital, lack of processing technology, and minimal supply chain and market awareness. Therefore, incentive policies, funding schemes, and technical training for farmers are needed to accelerate the adoption of EFB-based technology.

Regarding implementation strategy, the government and the industrial sector need to work together to strengthen processing infrastructure, tax incentives for EFB-based investment, and develop product standards to increase competitiveness in the global market. Based on the OECD report (2023), demand for biodegradable products increases by 25% per year, providing excellent opportunities for developing the EFB-based industry. If the supply chain can be optimized and policy support is strengthened, then by 2030, the EFB-based sector can contribute 5-7% of national palm oil farmer income growth and reduce unused EFB waste by 50%. In the future, further research needs to be done to improve the efficiency of EFB processing technology and develop a more inclusive business model for smallholders. Collaboration between academics, industry, and government is essential in driving EFB-based product innovation and expanding market access domestically and internationally. With the right strategy, EFB-based product diversification can be one of the long-term solutions to create a more sustainable, environmentally friendly palm oil industry that provides more equitable economic benefits for all stakeholders.

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