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Circular Packaging Innovation Using Pineapple Leaf Fiber (PALF) for Sustainable FMCG Systems

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ABSTRACT
The increasing dependence of the Fast Moving Consumer Goods (FMCG) industry on fossil-based plastic packaging presents significant environmental and regulatory challenges, particularly in countries with high consumption volumes and limited waste management capacity. Indonesia, as an agrarian nation, generates abundant agricultural residues that remain underutilized, including pineapple leaf waste. Pineapple Leaf Fiber (PALF) offers favorable mechanical properties and biodegradability, making it a promising alternative material for sustainable packaging applications. This study adopts a design-oriented applied engineering methodology to develop PALF-based smart composite packaging aligned with biological circular system principles. Pineapple leaf fibers were processed through mechanical decortication, surface treatment, and controlled drying, then incorporated into bio-based polymer matrices at 40–50% fiber content. Composite packaging structures were fabricated using compression molding or lamination techniques adaptable to existing FMCG production lines. Performance evaluation was conducted at laboratory and pilot scales (TRL 5–6), focusing on mechanical durability, moisture resistance, and manufacturability, alongside feasibility and techno-economic assessments. The findings indicate that PALF-based composites provide adequate mechanical strength and flexibility for both flexible packaging and protective layers, while bio-based barrier coatings effectively address moisture sensitivity without compromising biodegradability. Although initial production costs exceed conventional plastic packaging, long-term stability is supported by local raw material availability and reduced exposure to fossil-based price volatility. The study demonstrates that PALF smart composite packaging represents a viable pathway toward sustainable FMCG packaging, integrating material performance, circular resource utilization, and shared economic and environmental value creation.

Keywords: Biodegradable packaging; Circular economy; Pineapple leaf fiber; Smart composite materials; Sustainable FMCG packaging.

INTRODUCTION

Packaging is a fundamental component of the Fast Moving Consumer Goods (FMCG) industry, as it serves not only as a means of product protection but also as a critical element in distribution efficiency, storage stability, and brand communication to consumers. It protects products from physical damage and contamination, enables efficient storage and distribution, and acts as a primary interface between brands and consumers through labeling, information, and visual identity [1]. In FMCG markets characterized by high-volume production, rapid consumption cycles, and intense competition, packaging has become an essential element of modern consumption patterns [2]. However, the same characteristics that make packaging indispensable its ubiquity, disposability, and low unit cost have also positioned it at the core of one of the most pressing sustainability challenges facing the industry today.

The global FMCG system remains heavily dependent on fossil-based plastic packaging, most of which is designed for single-use applications. This dominant approach follows a linear take make dispose model, where raw materials are extracted, converted into packaging, used briefly, and then discarded with limited opportunities for recovery or reuse [3]. While this model has historically supported efficiency and cost optimization, it has also resulted in significant environmental externalities. Large volumes of packaging waste accumulate each year, overwhelming waste management systems and contributing to widespread pollution [4]. In 2019, the world produced 370 million tons of plastic, of which only 9% was recycled, 12% incinerated, and the rest ended up in the environment or landfills [5]. Packaging represents the largest share of global plastic waste, making it a critical intervention point for reducing environmental impacts associated with plastics.

From a sustainability perspective, the linear packaging model undermines efforts to conserve resources and reduce emissions. Virgin plastic production relies heavily on fossil fuels, contributing to greenhouse gas emissions across extraction, refining, and manufacturing stages [6]. At the end of life, packaging waste is often landfilled, incinerated, or leaked into natural environments, where it persists for decades and degrades into microplastics. These outcomes directly conflict with the principles of sustainable development, which emphasize resource efficiency, environmental protection, and intergenerational equity. Addressing packaging waste is therefore not only an environmental imperative but also a fundamental requirement for aligning FMCG systems with long-term sustainability goals.

In Indonesia, the sustainability challenge associated with packaging waste is particularly pronounced. Rapid population growth, urbanization, and rising household incomes have driven increased consumption of packaged FMCG products, especially food, beverages, and household necessities [7]. However, post-consumer waste management infrastructure has not expanded at the same pace. As a result, a large proportion of packaging waste is improperly managed, ending up in open dumping sites, waterways, or coastal ecosystems. These conditions exacerbate environmental degradation, increase flood risks, and pose public health concerns, particularly in densely populated urban areas [8]. The economic burden of waste management also places increasing pressure on local governments and communities.

Efforts to improve the sustainability of packaging have often focused on material-level solutions, such as lightweighting, increasing recycled content, or introducing alternative materials. While these strategies represent important steps forward, their impact remains limited when implemented in isolation. Sustainable packaging cannot be achieved solely through material substitution if the broader system of consumption, collection, and recovery remains unchanged [9]. Many alternative materials still face challenges related to cost, performance, infrastructure compatibility, and consumer acceptance [10]. Without systemic integration, even well-intentioned innovations risk reproducing the same linear outcomes as conventional plastics. A sustainability oriented transition in packaging requires a shift toward circular systems that consider the entire life cycle of materials. Circular packaging design prioritizes durability, recyclability, compostability, or reusability, depending on the intended application, and aligns material choices with existing or planned recovery pathways [11]. Such an approach supports responsible consumption and production by reducing waste generation and maximizing resource efficiency, in line with global sustainability frameworks. It also recognizes that packaging sustainability is not solely an environmental issue, but one that intersects with economic viability and social inclusion.

From a business perspective, integrating sustainability into packaging strategies can enhance long-term resilience and competitiveness. Reducing reliance on fossil-based materials can mitigate exposure to volatile oil prices and regulatory risks, while circular packaging models can create new value streams through material recovery and local sourcing. For consumers, sustainable packaging can strengthen trust and engagement by aligning product choices with environmental values. At the societal level, sustainability-driven packaging solutions can contribute to job creation, capacity building, and improved environmental outcomes, particularly when local resources and communities are involved. Ultimately, the scale of packaging-related sustainability challenges demands a holistic and forward looking approach. Packaging must be reimagined not as a disposable by product of consumption, but as an integral component of sustainable value creation [12]. This requires collaboration across the FMCG value chain, from material sourcing and design to manufacturing, distribution, consumption, and end-of-life management. By embedding sustainability principles into packaging systems, the FMCG industry has the opportunity to significantly reduce its environmental footprint, support social and economic development, and contribute meaningfully to a more sustainable future.

Table 1. Scale of Packaging and Plastic Waste Challenges

Indicator	**Quantitative Value**
Contribution of packaging to global plastic waste	±40% of total global plastic waste
Total waste generation in Indonesia (2023)	±56.6 million tons/year
Plastic waste generation in Indonesia	±10.8 million tons/year
Mismanaged plastic waste in Indonesia	±6.6 million tons/year

Indicator	Quantitative Value
Percentage of packaging discarded after single use (global)	±80%
Average per capita plastic packaging waste (European Union)	±35 kg/person/year

Source: [13][14]

The data indicate that packaging represents a critical leverage point in efforts to reduce plastic waste and transition toward a circular economy. Therefore, a more systemic approach is required, not merely by replacing plastic materials, but by designing packaging that, from the outset, takes into account material life cycles, consumer behavior, and the readiness of waste management systems [15]. Indonesia has a strategic opportunity to develop sustainable packaging solutions based on local resources. As an agrarian country, Indonesia generates large volumes of agricultural waste each year, one of which is pineapple leaves. Pineapple leaf waste generally has little to no economic value and is often burned or left to decompose, practices that contribute to additional emissions and environmental problems [16]. In fact, pineapple leaves contain Pineapple Leaf Fiber (PALF), a natural fiber characterized by high tensile strength, low weight, and significant potential for application as a raw material for natural fiber composite packaging.

The utilization of PALF as a packaging material offers a smart materials approach that focuses not only on material properties but also on integration within a circular system. Under this approach, agricultural waste is transformed into a high-value input within the FMCG supply chain. Pineapple leaf fibers are processed into composite materials that are strong and functional during the product's use phase, while remaining biodegradable after disposal. As such, the material is engineered to deliver strength during use and natural degradability once its primary function has been fulfilled. From a circular economy perspective, PALF-based packaging solutions create new value flows that are restorative and regenerative in nature. Agricultural waste that was previously considered valueless becomes an additional source of income for farmers, creates new employment opportunities in material processing, and reduces industry dependence on fossil-based plastic raw materials. From a business standpoint, this approach enables FMCG companies to enhance supply chain resilience, mitigate risks associated with oil price volatility, and strengthen brand differentiation amid growing consumer awareness of sustainability issues.

Furthermore, the development of PALF-based packaging contributes directly to the achievement of the Sustainable Development Goals (SDGs) [17] [18][19]. This solution supports SDG 12 by reducing waste generation and improving resource-use efficiency, SDGs 13 by lowering emissions associated with fossil-based plastics and agricultural waste burning, and SDGs 8 by creating new and inclusive economic opportunities. In addition, by reducing land pollution and agricultural waste burning practices, this solution also contributes to the protection of terrestrial ecosystems, as reflected in SDGs 15. In conclusion, the development of FMCG packaging based on Pineapple Leaf Fiber addresses not only material-related challenges but also offers a systemic solution that integrates technological innovation, circular economy principles, and social and environmental impacts. This approach demonstrates that effective sustainable packaging must be designed in alignment with local contexts, leverage available resources, and generate long-term value for businesses, communities, and the environment alike.

METHODS

This study employs a design-oriented applied engineering method to develop and evaluate Pineapple Leaf Fiber (PALF)–based smart composite packaging for Fast Moving Consumer Goods (FMCG) applications within a biological circular system framework. The method integrates material preparation, composite formulation, performance validation, and feasibility analysis to ensure technical relevance, scalability, and sustainability alignment. Pineapple leaf waste sourced from post-harvest agricultural activities in Kampar Regency, Riau Province, was utilized as the primary reinforcement material. The fibers were obtained through mechanical decortication, followed by washing, alkaline treatment, and controlled drying to achieve moisture content below 10%, ensuring compatibility with composite processing and stable material performance. The prepared PALF was then combined with a bio-based polymer matrix (PLA or starch-based blends) at a fiber content of approximately 40–50% by weight, along with natural plasticizers and additives to enhance flexibility and mechanical resilience.

Composite sheets were fabricated using compression molding or lamination techniques adaptable to existing FMCG packaging production lines. For applications requiring moisture protection, a thin bio-based barrier coating (wax- or chitosan-based) was applied, with formulation adjusted according to product-specific functional requirements while maintaining biodegradability. Material and packaging performance were evaluated at laboratory and pilot scales corresponding to Technology Readiness Levels (TRL) 5–6, focusing on mechanical durability, moisture resistance, and manufacturability under realistic operating conditions. In parallel, a feasibility and scalability assessment was conducted, encompassing raw material availability, process adaptability, and techno-economic estimation based on local agricultural waste conditions. Sustainability performance was assessed qualitatively through a life-cycle-oriented perspective and the Creating Shared Value framework, examining environmental impact reduction, supply chain resilience, and socio-economic benefits for upstream agricultural communities.

RESULT AND DISCUSSION

The development of PALF Smart Composite Packaging is grounded in the utilization of agricultural waste as a high-value packaging material designed to address sustainability challenges within the Fast Moving Consumer Goods (FMCG) industry. In the context of Indonesia as an agrarian country, pineapple leaves represent an abundant agricultural residue that remains largely underutilized. Common practices such as disposal or open burning of pineapple leaves not only reflect inefficient resource use but also contribute to environmental degradation. Consequently, the development of packaging based on Pineapple Leaf Fiber (PALF) offers a locally relevant material approach while meeting the functional requirements of industrial applications. PALF possesses favorable mechanical characteristics, including high tensile strength and relatively low density, enabling its use as a natural fiber composite material. In packaging development, PALF fibers are processed and combined with bio-based matrices to form a stable and versatile composite structure. This approach allows the material to deliver the mechanical performance required during the product's service life while maintaining biodegradability once the packaging is no longer in use. As such, the material is engineered to fulfill protective functions without creating long-term environmental burdens.

PALF Smart Composite Packaging is classified as a smart material due to its properties and functions being deliberately designed in accordance with the different stages of the product life cycle. During the use phase, the material is formulated to be strong, mechanically resilient, and capable of protecting products from damage throughout distribution and consumption. After the use phase, the material is able to decompose naturally through biological processes, aligning with bio-based circular systems. This approach emphasizes the importance of material design that considers the entire life cycle, rather than focusing solely on in-use performance.

The integration of PALF within a biological circular system enables a more sustainable material flow. Pineapple leaf fibers derived from agricultural waste are transformed into value-added packaging materials, utilized within FMCG consumption cycles, and subsequently returned to the environment as biodegradable matter. This cycle creates a mutually beneficial relationship between the agricultural and industrial sectors, in which waste from one sector becomes a productive input for another. Packaging is thus no longer positioned as the endpoint of consumption, but as an integral component of a restorative and regenerative system. From an application perspective, PALF Smart Composite Packaging can be utilized in various packaging formats tailored to the functional requirements of FMCG products. One primary application is flexible composite packaging, commonly used for dry foods, powders, and everyday consumer goods. The composite structure enables the material to remain flexible and lightweight while providing sufficient strength to maintain product integrity. This application demonstrates that natural fiber-based materials can be adapted to meet the demands of modern packaging systems that have traditionally been dominated by flexible plastics.

In addition, PALF can be applied as a protective layer in both primary and secondary packaging. In this role, PALF fibers enhance the structural strength of packaging, protect products from impact and compression during logistics, and indirectly contribute to extended product shelf life through improved physical protection. This approach allows PALF to be integrated gradually into existing packaging systems, facilitating a smoother transition toward more sustainable materials without disrupting industrial operations. The application of PALF Smart Composite Packaging extends beyond technical material performance to include a design approach grounded in function and impact. Packaging design considers material efficiency, manufacturability, and communicability to consumers. By leveraging the visual and tactile qualities of natural fibers, the packaging can implicitly convey sustainability values, strengthening the connection between the product, the material, and the environment. As a result, packaging serves not only as a product protector but also as a medium for consumer education and the expression of sustainability values.

PALF Smart Composite Packaging represents a material development approach that integrates local resource utilization, functional performance, and alignment with biological circular systems. By transforming agricultural waste into strong and biodegradable packaging materials, this solution demonstrates that packaging innovation can be designed to meet industrial requirements while supporting environmental sustainability. This approach underscores the need for systemic thinking in future packaging development, linking materials, design, and life cycle considerations into a cohesive and sustainable framework.

The development of PALF Smart Composite Packaging is supported by the availability of mature natural fiber processing technologies that have been proven applicable at industrial scale. Fiber extraction and processing methods for natural fibers such as PALF have long been utilized in various non-textile and composite material applications, and therefore do not require radical technological breakthroughs. Within the context of FMCG packaging manufacturing, these technologies can be gradually integrated into existing production processes, either through modifications to current production lines or through collaboration with bio-based composite material manufacturers. The implementation strategy is designed to be progressive in order to minimize technical and operational risks. The initial phase focuses on pilot projects for high-volume FMCG products with relatively stable product characteristics, such as dry food items or household goods. Through these pilot projects, material performance can be evaluated under real operating conditions, including mechanical durability, compatibility with packaging processes, and market response. Insights gained from this initial phase provide a foundation for refining material design and production processes before wider-scale deployment.

Raw material availability is a critical factor in the long-term sustainability of this solution. Pineapple leaves, as agricultural waste, are abundantly available and renewable in line with agricultural production cycles. Their utilization does not compete with food production needs and does not require land expansion, thereby avoiding the environmental risks commonly associated with primary raw material sourcing. This condition provides a strong foundation for the long-term development of PALF-based packaging, particularly in countries with significant pineapple production such as Indonesia. Furthermore, the material characteristics of PALF enable its application across a wide range of FMCG product categories. Flexibility in composite design allows the material to be tailored for both primary and secondary packaging requirements, as well as for various packaging formats. This approach supports a gradual plastic substitution strategy, in which natural fiber-based materials do not need to immediately replace all plastic components, but can first be applied to packaging elements with the highest relevance and impact. In this way, the transition toward more sustainable packaging can be managed in a realistic and controlled manner.

In the long term, the PALF-based packaging development approach demonstrates a high degree of adaptability to external changes. Increasingly stringent regulations on single-use plastics can be addressed more flexibly through the adoption of bio-based materials aligned with environmental policies. From a market perspective, growing consumer awareness of sustainability issues is driving higher demand for environmentally and socially responsible packaging. At the same time, future advancements in material technologies can be continuously integrated to enhance PALF performance without compromising the core sustainability principles of the approach. Overall, the development of PALF Smart Composite Packaging is not only relevant to current industry needs but is also designed to adapt to future dynamics in industry practices, regulatory frameworks, and material technologies. The combination of a phased implementation strategy, sustainable raw material availability, and cross-category application flexibility positions this solution as a strategic component of a long-term transition toward a more responsible and resilient FMCG packaging system.

Table 2. Technical Implementation Framework for PALF-Based Packaging

Aspect	Engineering-Oriented Description
Feasibility	PALF processing utilizes established mechanical decortication, alkaline treatment, and fiber drying techniques, followed by composite formation through compression molding or lamination, which can be integrated into existing FMCG packaging manufacturing lines with minimal equipment modification.
Scalability	Material scale-up is supported by continuous availability of pineapple leaf biomass, modular fiber processing units, and adaptable composite formulations that allow thickness, strength, and barrier properties to be adjusted for different FMCG packaging requirements.
Plan Clarity	The implementation roadmap consists of laboratory material characterization, pilot-scale production (TRL 5–6), industrial line trials, quality and performance validation (mechanical strength, moisture resistance), and progressive deployment across product categories.

5. Impacts and Discussion of Results

The development of PALF Smart Composite Packaging aligns with the Creating Shared Value approach, which positions economic and social value creation as mutually reinforcing processes. This solution does not frame sustainability merely as an additional cost, but rather as a long-term business strategy that strengthens corporate competitiveness while delivering tangible benefits to society and the environment. By utilizing locally available agricultural waste as a high-value packaging material, this approach connects the interests of the FMCG industry with improvements in upstream community livelihoods and ecosystem protection. From a cost perspective, PALF-based packaging exhibits a slightly higher cost structure during the early stages of development compared to conventional plastic packaging. This is primarily driven by the need for investment in material research, performance testing, and adaptation of natural fiber composite manufacturing processes. However, over the long term, the cost structure tends to be more stable, as the primary raw material is derived from local agricultural waste and is therefore insulated from global oil price volatility. This stability in supply and cost provides a strategic advantage, particularly in the context of increasing supply chain risks associated with fossil-based plastics and growing regulatory pressure on single-use plastic packaging. Furthermore, the added value in the form of strengthened sustainable brand positioning and regulatory readiness has the potential to offset the initial cost gap and generate significant indirect benefits.

Material durability represents a critical requirement for FMCG packaging applications, and the PALF-based approach is designed to meet this demand. Pineapple leaf fiber exhibits relatively high tensile strength compared to many other natural fibers, enabling adequate mechanical performance. In practical applications, PALF is not used as a single fiber material but as a reinforcement within a bio-based composite matrix. This composite configuration allows for more effective load distribution and enhances resistance to mechanical stress during distribution and storage. As a result, PALF Smart Composite Packaging is suitable for both flexible packaging applications and protective layers in primary and secondary FMCG packaging.

Figure 2. The production of pineapple leaf fiber (PALF) reinforced biocomposites involves a systematic process. [20]

Moisture management is a common challenge for fiber-based packaging materials, particularly for food and beverage products. To address this challenge, PALF Smart Composite Packaging incorporates a thin bio-based coating that functions as a moisture barrier. This coating is selectively engineered to protect the product without compromising the overall biodegradability of the material. The formulation and thickness of the barrier layer can be adjusted according to product characteristics, enabling application flexibility across multiple FMCG categories. This approach ensures a balanced trade-off between functional performance and environmental responsibility. From a scalability perspective, the PALF-based approach has a strong foundation for gradual implementation. Indonesia, as one of the world's major pineapple-producing countries, generates abundant and continuous pineapple leaf waste throughout the year. This availability supports the development of a stable supply chain without the need for land expansion or interference with food production. In addition, natural fiber processing technologies and composite manufacturing processes are already available and can be adapted in a modular manner, allowing production capacity to be scaled progressively in line with market demand and industrial readiness.

This phased development strategy is consistent with risk mitigation principles in the FMCG industry. Implementation can begin with high-volume products that have relatively simple technical requirements and then expand to other categories as efficiency and operational experience improve. In this way, the transition toward more sustainable packaging is positioned not as a disruption, but as a planned and evolutionary transformation of the existing system.

Table 3. Raw material prices, processing steps, and production costs of PALF Smart Composite Packaging specific to Riau Province Kampar Regency Kualu Nenas Village.

Stage / Component	**Technical Description**	**Unit**	**Estimated Cost (IDR)**	**Remarks**
Primary Raw Material	Post-harvest pineapple leaf waste	kg of leaves	300 – 600	Farmer incentive; previously had no economic value
	Biomass conversion	10 kg leaves → 1 kg PALF	–	Average PALF yield
Fiber Extraction	Mechanical decortication	per kg PALF	4,000 – 6,000	Fiber separation from leaves
	Washing & initial treatment	per kg PALF	2,000 – 3,000	Improves fiber–matrix adhesion
	Fiber drying	per kg PALF	2,000 – 3,000	Moisture content <10%
	Total dried PALF cost		**per kg PALF**	**13,000 – 20,000**
Composite Material	PALF fiber (40–50%)	per kg packaging	7,000 – 10,000	Primary reinforcement
	Bio-based polymer matrix	per kg packaging	35,000 – 45,000	PLA / starch-based blend
	Plasticizer & natural additives	per kg packaging	5,000 – 8,000	Flexibility and performance enhancement
Manufacturing Process	Compounding & mixing	per kg packaging	4,000 – 6,000	Material homogenization
	Sheet forming / molding	per kg packaging	4,000 – 6,000	Compression molding / lamination

Stage / Component	Technical Description	Unit	Estimated Cost (IDR)	Remarks
Barrier & Finishing	Bio-based moisture barrier coating	per kg packaging	5,000 – 7,000	Wax- or chitosan-based
	Cutting & forming	per kg packaging	2,000 – 3,000	Final packaging shape
Overhead & Quality Control	Quality control & material loss	per kg packaging	3,000 – 5,000	FMCG quality standards
	Logistics & handling	per kg packaging	2,000 – 3,000	Initial distribution
TOTAL COST	**PALF Smart Composite Packaging**	**per kg**	**65,000 – 90,000**	Pilot–early commercial scale
Cost Benchmark	Conventional PE/PP plastic packaging	per kg	30,000 – 45,000	Price volatility due to fossil-based inputs
Projected Cost (Scaled)	Optimized PALF packaging	per kg	50,000 – 70,000	Post scale-up
Shared Value Impact	Additional farmer income	per ton of leaves	± 300,000 – 600,000	Local economic impact
	Agricultural waste diverted	per year	Tens of tons	Environmental and social benefits

Source: Kampar Regency, Kualu Nenas Village.

The table 3 represent engineering–economic estimates based on local agricultural waste conditions and do not reflect official market prices. PALF Smart Composite Packaging has been developed as a material and packaging system approach that integrates functional performance with sustainability principles and economic feasibility. From a cost perspective, PALF-based materials require a relatively higher initial investment compared to conventional plastic packaging, particularly for material development, performance testing, and natural fiber processing. However, the long-term cost structure tends to be more stable, as the primary raw material is derived from locally sourced, renewable agricultural waste and is not affected by fluctuations in fossil-based input prices. This stability provides a strategic advantage in the FMCG sector, which increasingly faces global supply chain uncertainties and heightened regulatory pressure on single-use plastics.

From a technical standpoint, utilizing PALF as a composite material enables the achievement of mechanical properties suitable for FMCG packaging, both for flexible applications and as protective layers. Pineapple leaf fibers exhibit relatively high tensile strength, and when combined with a bio-based polymer matrix, they produce packaging structures capable of withstanding pressures encountered during distribution and storage. Moisture resistance challenges are addressed through a thin bio-based barrier layer, which can be tailored to specific product characteristics, ensuring protective functionality without compromising the material's biodegradability. The abundant availability of pineapple leaf waste and the readiness of natural fiber processing technologies support a gradual and controlled implementation of this solution. Overall, this approach aligns with the Creating Shared Value concept, where economic value creation is paired with environmental impact reduction and social empowerment, making it highly relevant for the development of long-term sustainable FMCG packaging systems. While PALF-based packaging has a slightly higher upfront cost than conventional plastic, its long-term stability, local sourcing, regulatory readiness, and shared value creation significantly outweigh the initial cost gap.

Properties	Source				
	George et al., 1995	George et al.,1998	Luo and Netravalli*, 1999	George et al., 2001	Leão et al., 2015*
Physical Properties					
Cell length (mm)	-	-	-	-	-
Diameter (μm)	-				5.0-30.0
Moisture content (%)	-	-	-	-	-
Vicat softening point (°C)	-	104.0	-	-	-
Density (gcm^{-3})	1.526	1.526	-		1.44
Mechanical Properties					
Tensile strength (MPa)	170.0	170.0	-	-	170
Ultimate tensile strength (MPa)	-	-	-	413-1627	-
Young's Modulus (MPa)	6.26	6.26	-	-	6.26
Elongation at break (%)	1.6	3.0	-	0.8 - 1	1.6
Flexural Modulus	-	-	-	0.24 - 0.40	-

Figure 3. Properties of pineapple leaf fiber (PALF). [21]

PALF Smart Composite Packaging reflects an integrated sustainability approach in which economic value creation goes hand in hand with social and environmental impact. This solution demonstrates that packaging innovation not only responds to market demands and regulatory requirements, but also contributes to the development of more responsible production and consumption systems. Within the Creating Shared Value framework, packaging is no longer merely a means of product protection, but becomes a transformative medium that connects industry, communities, and the environment within a mutually reinforcing ecosystem.

CONCLUSION

PALF Smart Composite Packaging exemplifies a holistic approach to sustainable packaging in the FMCG sector by integrating functional performance, environmental responsibility, and socio-economic value creation. By utilizing locally available agricultural waste specifically pineapple leaves this solution transforms what was previously considered valueless biomass into a high-performance material suitable for both flexible and protective packaging applications. The material's mechanical strength, biodegradability, and adaptability across product categories enable a circular approach to packaging, reducing reliance on fossil-based plastics while maintaining product protection and supply chain efficiency. This alignment with circular economy principles ensures that packaging is no longer an isolated waste stream but an active contributor to regenerative and restorative material flows.

From an economic and strategic perspective, PALF-based packaging requires slightly higher initial investments compared to conventional plastics due to research, testing, and natural fiber processing. However, the long-term cost structure is more stable, as raw material sourcing is locally renewable and insulated from global oil price volatility. This stability, combined with enhanced brand positioning, regulatory readiness, and shared value creation for upstream communities, offsets early-stage cost differentials. Technologically, PALF composites achieve the mechanical and moisture-resistance properties required for FMCG applications, while the modular and scalable implementation strategy ensures a controlled and phased transition. Ultimately, PALF Smart Composite Packaging demonstrates that sustainable innovation in FMCG packaging can simultaneously address environmental challenges, support local economies, and reinforce long-term business resilience, embodying a truly integrated model of Creating Shared Value.

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