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DEVELOPMENT AND FIELD TESTING OF BIODEGRADABLE PACKAGING MATERIALS FROM PLANTAIN PEELS AND CORN HUSKS IN OYO AND ONDO STATES, NIGERIA

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Abstract

The increasing environmental burden of plastic waste has intensified the search for sustainable and biodegradable alternatives, particularly in developing economies where waste management systems are underdeveloped. This study develops and field-tests biodegradable packaging materials derived from plantain peels and corn husks in Oyo and Ondo States, Nigeria. Adopting an experimental and field-evaluation research design, agro-waste materials were processed using green chemistry techniques to extract starch and lignocellulosic fibers, which were subsequently formulated into biodegradable films using natural plasticizers. Laboratory analyses evaluated physicochemical properties including tensile strength, thickness, water resistance, and thermal stability, while field trials were conducted with small-scale food vendors to assess usability, durability, and user acceptance. Results indicate that the developed biofilms exhibit competitive mechanical strength (mean tensile strength = 18.6 MPa) and satisfactory biodegradability, decomposing within 21–28 days under natural conditions. Field evaluations reveal high user acceptance, particularly for dry food packaging, although limitations were observed in moisture resistance under prolonged exposure. The study demonstrates the viability of converting agricultural waste into functional packaging materials, contributing to circular bioeconomy practices and sustainable waste management. It concludes that locally sourced biodegradable packaging can serve as a cost-effective alternative to conventional plastics and recommends scaling through MSME-driven production and policy support. The findings provide actionable insights for environmental sustainability, green innovation, and plastic waste reduction in Nigeria and similar contexts.

Keywords: Biodegradable packaging; Agro-waste; Plantain peels; Corn husks; Bioplastics; Circular economy; Sustainable materials; Nigeria

1.0 Introduction

The escalating global dependence on plastic packaging has resulted in a severe environmental crisis, with persistent accumulation of non-biodegradable waste posing significant threats to ecosystems, public health, and climate stability. Conventional petroleum-based plastics are highly resistant to degradation, often persisting in the environment for decades and contributing to soil contamination, marine pollution, and greenhouse gas emissions (Selvam et al., 2025). The food packaging sector, in particular, represents a major contributor to this problem due to the widespread use of single-use plastics, which are valued for their durability, low cost, and convenience but are environmentally unsustainable. Consequently, there is a growing global shift toward sustainable materials and circular economy approaches that prioritize renewable resources, waste valorization, and biodegradability.

Biodegradable packaging materials have emerged as a promising alternative to conventional plastics, offering the potential to decompose naturally under environmental conditions while reducing reliance on fossil-based resources. Recent advances in materials science and green chemistry have facilitated the development of biopolymers derived from agricultural residues, including starch, cellulose, and lignocellulosic fibers, which exhibit favorable mechanical and barrier properties suitable for packaging applications (Kossalbayev et al., 2025). These materials not only mitigate environmental pollution but also support circular bioeconomy models by converting agro-waste into value-added products. The increasing interest in sustainable packaging is further driven by regulatory pressures, consumer awareness, and global sustainability frameworks such as the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production).

Agricultural by-products such as plantain peels and corn husks represent abundant, low-cost, and underutilized resources with significant potential for biodegradable material production. Corn husks, for instance, contain high levels of cellulose (approximately 38–40%), hemicellulose, and lignin, making them suitable for fiber-based packaging applications with good tensile strength and biodegradability characteristics (Azrial et al., 2025). Similarly, plantain peels are rich in starch and pectin, which contribute to film-forming ability and flexibility in bioplastic formulations (Taweechat et al., 2021). Empirical studies have demonstrated that such agro-wastes can be processed into biodegradable films and paper-based packaging materials with properties comparable to synthetic plastics when properly modified with plasticizers and cross-linking agents. Moreover, blending lignocellulosic fibers with starch-based matrices has been shown to significantly enhance mechanical strength, thermal stability, and barrier performance (Garcia-Arteaga et al., 2026).

Beyond their physicochemical advantages, the utilization of plantain peels and corn husks aligns with sustainability principles by addressing two critical challenges simultaneously: agricultural waste management and plastic pollution. Globally, millions of tonnes of agricultural residues are generated annually, much of which remains underutilized or is disposed of through open burning, contributing to environmental degradation (Selvam et al., 2025). Converting these residues into biodegradable packaging materials offers a viable pathway for waste reduction, resource efficiency, and economic value creation, particularly in developing economies where agricultural production is high and waste management systems are limited.

In Nigeria, the proliferation of single-use plastics especially in food packaging has exacerbated environmental challenges, including clogged drainage systems, urban flooding, and soil contamination. Despite growing policy efforts to regulate plastic use, including initiatives such as Extended Producer Responsibility (EPR), the adoption of sustainable alternatives remains limited due to inadequate research, lack of pilot-scale production, and insufficient market integration. At the same time, Nigeria's agricultural sector produces substantial quantities of plantain and maize residues, particularly in Southwestern states such as Oyo and Ondo, creating an opportunity for localized production of biodegradable packaging materials.

While previous studies have explored the development of bioplastics from agricultural residues, many have focused primarily on laboratory-scale experimentation without extending to real-world application and user validation. For instance, studies on corn husk-based packaging have demonstrated promising mechanical properties and biodegradability but highlight challenges related to scalability, durability, and user acceptance (Azrial et al., 2025). Similarly, starch-based films derived from plant residues often require optimization to improve moisture resistance and functional performance under practical conditions. These limitations underscore the need for integrated research that combines material development with field testing and stakeholder engagement.

Against this backdrop, this study seeks to develop and field-test biodegradable packaging materials derived from plantain peels and corn husks in Oyo and Ondo States, Nigeria. By integrating laboratory experimentation with real-life usability assessments, the study aims to evaluate the physicochemical performance, biodegradability, and user acceptance of the developed materials. The research contributes to advancing sustainable materials innovation, promoting circular bioeconomy practices, and providing evidence-based solutions for reducing plastic pollution in Nigeria and similar developing contexts.

2.0 Literature Review

Although Human Capital Theory and Financial Capability Theory are traditionally applied in socio-economic studies, their underlying logic of resource optimization, capability development, and value creation can be extended to sustainable materials innovation. In this study, the theoretical grounding is primarily anchored in the Circular Bioeconomy Framework and Sustainable Materials Transition Theory, which emphasize the transformation of waste into value-added products through innovation, knowledge application, and system-level change (Geissdoerfer et al., 2017; Kirchherr et al., 2017). The circular bioeconomy advocates the efficient use of biological resources to create sustainable products while minimizing waste and environmental impact. It aligns with the principle that waste materials, such as agricultural residues, can be reprocessed into economically viable and environmentally friendly products (D'Amato et al., 2020). Within this framework, agro-wastes like plantain peels and corn husks are not viewed as waste but as renewable feedstocks capable of supporting sustainable industrial production. Furthermore, Sustainable Materials Transition Theory highlights the shift from fossil-based materials to renewable and biodegradable alternatives driven by environmental concerns, regulatory pressures, and technological advancements (Bocken et al., 2016). This transition requires not only technological innovation but also stakeholder engagement, market acceptance, and policy support, all of which are critical to the adoption of biodegradable packaging in developing economies such as Nigeria.

Biodegradable packaging materials are defined as materials capable of decomposing into natural substances such as water, carbon dioxide, and biomass through microbial activity under environmental conditions (Mohanty et al., 2022). These materials are typically derived from renewable resources such as starch, cellulose, proteins, and lipids, and are increasingly used in food packaging due to their eco-friendly properties and reduced environmental footprint. Recent advances in biopolymer science have enabled the development of biodegradable films with improved mechanical strength, thermal stability, and barrier properties comparable to conventional plastics (Kossalbayev et al., 2025). These improvements are largely attributed to the incorporation of reinforcing agents such as lignocellulosic fibers and the use of plasticizers to enhance flexibility and durability. However, challenges remain in achieving optimal performance, particularly in terms of moisture resistance and long-term durability. Studies have shown that while starch-based bioplastics are biodegradable, they are often sensitive to water and may require modification through blending or chemical treatment to enhance their functional properties (Garcia-Arteaga et al., 2026). These limitations highlight the need for continued research to optimize formulations and improve performance characteristics.

The use of agricultural waste as feedstock for biodegradable materials has gained significant attention due to its dual benefits of waste management and resource efficiency. Agro-wastes such as plantain peels and corn husks are rich in cellulose, hemicellulose, lignin, and starch, making them suitable for the production of biopolymers and composite materials (Adeyemi et al., 2020; Okonkwo et al., 2021). Plantain peels, in particular, contain high levels of starch and pectin, which facilitate film formation and contribute to the flexibility and cohesiveness of biodegradable films. Similarly, corn husks are lignocellulosic in nature and provide structural reinforcement, enhancing the tensile strength and thermal stability of composite materials. The combination of these materials in bio-composite formulations has been shown to produce packaging materials with improved mechanical and functional properties (Fasakin & Odunayo, 2022). Empirical studies have demonstrated that agro-waste-derived bioplastics can achieve tensile strength values comparable to low-density polyethylene when properly processed (Mohanty et al., 2022). However, most of these studies are limited to laboratory-scale experiments, with minimal focus on real-world applications and scalability, particularly in developing countries.

The performance of biodegradable packaging materials is largely determined by their physicochemical and mechanical properties, including tensile strength, elongation at break, thickness, water absorption, and thermal stability. These properties influence the suitability of the materials for different packaging applications. Tensile strength is a critical parameter, as it determines the material’s ability to withstand mechanical stress during handling and transportation. Studies have shown that the incorporation of lignocellulosic fibers into starch-based matrices significantly improves tensile strength and reduces brittleness (Garcia-Arteaga et al., 2026). Similarly, the use of plasticizers such as glycerol and sorbitol enhances flexibility but may reduce strength if not properly optimized. Water resistance is another key factor, particularly for food packaging applications. Biodegradable films derived from starch are inherently hydrophilic, making them susceptible to moisture absorption. To address this limitation, researchers have explored various modification techniques, including chemical cross-linking and blending with hydrophobic materials (Kossalbayev et al., 2025). Thermal stability is also essential, as it determines the material's resistance to temperature variations during storage and use. Overall, achieving a balance between these properties remains a key challenge in biodegradable packaging research.

While laboratory testing provides critical insights into material properties, field testing and user acceptance are essential for evaluating the practical viability of biodegradable packaging materials. User acceptance is influenced by factors such as appearance, durability, cost, and ease of use, which determine the likelihood of adoption in real-world settings. Studies have shown that consumer perception plays a significant role in the adoption of sustainable packaging. Materials that closely resemble conventional plastics in terms of functionality and aesthetics are more likely to be accepted by users (Bocken et al., 2016). In developing economies, cost considerations are particularly important, as users may be reluctant to adopt alternatives that are significantly more expensive than conventional options. Field testing also provides valuable feedback on material performance under real environmental conditions, including exposure to moisture, temperature variations, and mechanical stress. However, there is a notable gap in the literature regarding field-based evaluations of biodegradable packaging in African contexts, particularly in Nigeria.

The development of biodegradable packaging materials has significant environmental and socio-economic implications. From an environmental perspective, these materials contribute to reducing plastic pollution, lowering carbon emissions, and promoting sustainable waste management practices (UNEP, 2022). From a socio-economic standpoint, the use of agro-waste as feedstock creates opportunities for value addition, job creation, and entrepreneurship, particularly in rural and agricultural communities. This aligns with the principles of the circular economy, which emphasize resource efficiency and economic sustainability (D'Amato et al., 2020). In Nigeria, the adoption of biodegradable packaging materials could support MSMEs, reduce reliance on imported plastics, and promote local innovation. However, achieving these benefits requires supportive policies, investment in research and development, and stakeholder engagement.

Despite significant progress in biodegradable materials research, several gaps remain. First, most studies focus on laboratory-scale development without extending to field testing and real-world application, limiting their practical relevance. Second, there is limited research on the use of locally available agro-wastes such as plantain peels and corn husks in Nigeria, despite their abundance. Third, user acceptance and market viability of biodegradable packaging materials remain underexplored, particularly in developing economies. This study addresses these gaps by integrating material development, laboratory testing, and field evaluation within a single research framework. By focusing on locally available resources and engaging end-users in real-world testing, the study provides a comprehensive assessment of the feasibility and sustainability of biodegradable packaging materials. The study contributes to advancing knowledge in sustainable materials science, supports circular bioeconomy practices, and provides practical insights for reducing plastic pollution in Nigeria and similar contexts.

3.0 Methodology

This study adopted an experimental and field-evaluation design integrated with statistical modelling to develop and validate biodegradable packaging materials from plantain peels and corn husks in Oyo and Ondo States, Nigeria. Agro-wastes sourced from Ibadan and Akure were washed, dried, milled, and processed using green chemistry methods (aqueous extraction and alkaline pulping) to obtain starch and lignocellulosic fibers, which were blended with natural plasticizers (glycerol, sorbitol) and cast into films. Laboratory tests evaluated physicochemical and mechanical properties including thickness, tensile strength, elongation, water resistance, thermal stability, and biodegradability (soil burial, 28 days), benchmarked against polyethylene standards. Field trials involved 60 small-scale vendors who tested the materials for two weeks, with data collected on usability, durability, appearance, cost perception, and acceptability using structured questionnaires and interviews. Quantitative analysis using SPSS (v27) included descriptive statistics, t-tests, and regression, while PLS-SEM (SmartPLS 4) assessed relationships among Material Quality (MQ), Functional Performance (FP), and User Acceptance (UA), with reliability ($\alpha \geq 0.70$, CR ≥ 0.70, AVE ≥ 0.50) and structural paths tested via bootstrapping (5,000 resamples; SRMR < 0.08) (Hair et al., 2022; Kline, 2023). Qualitative data were analyzed thematically and integrated through triangulation, while ethical standards and robustness checks (VIF < 5, sensitivity tests) ensured validity and generalizability.

4.0 Results and Discussion

Table 1: Laboratory Performance of Biodegradable Films

Parameter	**Mean Value**	**Polyethylene Benchmark**	**Remarks**
Thickness (mm)	0.32	0.25–0.35	Comparable
Tensile Strength (MPa)	18.60	20–30	Moderate
Elongation at Break (%)	21.4	100–500	Low flexibility
Water Absorption (%)	34.2	<10	High
Thermal Stability (°C)	185	200–300	Moderate
Biodegradation (Days)	21–28	Non-biodegradable	Excellent

Table 1 presents the physicochemical and mechanical performance of the developed biodegradable films relative to conventional polyethylene. The thickness of the films (0.32 mm) falls within the acceptable range for commercial packaging, indicating uniform film formation and effective casting. The tensile strength (18.60 MPa), although slightly below polyethylene standards, demonstrates adequate mechanical integrity for light-duty packaging applications such as wrapping dry food items. This suggests that the combination of plantain starch and corn husk fibers contributed positively to structural reinforcement, consistent with prior findings that lignocellulosic fibers enhance tensile properties. However, elongation at break (21.4%) is significantly lower than polyethylene, indicating limited flexibility and a tendency toward brittleness under stress. This limitation can be attributed to the high fiber content and relatively low plasticizer ratio, which restrict polymer chain mobility. Water absorption (34.2%) remains a major limitation, reflecting the hydrophilic nature of starch-based biopolymers. This implies that the material is less suitable for high-moisture packaging without further modification. Thermal stability (185°C) is moderately adequate, indicating resistance to typical environmental temperatures but limited suitability for high-heat applications. Notably, biodegradation within 21–28 days represents a significant environmental advantage over conventional plastics, confirming the eco-friendly potential of the material. Overall, the results demonstrate that while the developed films are not yet equivalent to polyethylene in all properties, they are viable for specific applications and can be further optimized.

Table 2: User Acceptability Ratings (n = 60)

Parameter	Mean Score	Std. Dev	Interpretation
Ease of Use	3.28	0.62	High
Appearance	3.12	0.66	Good
Durability	2.89	0.71	Moderate
Moisture Resistance	2.54	0.78	Low
Overall Acceptability	3.05	0.68	Moderate-High

Table 2 presents the field evaluation results based on user feedback from small-scale vendors. Ease of use recorded the highest mean score (3.28), indicating that the developed packaging materials are user-friendly and compatible with existing packaging practices. This is a critical factor for adoption, as ease of handling directly influences user willingness to transition from conventional plastics. Appearance also received favorable ratings (3.12), suggesting that the biofilms meet basic aesthetic expectations. This is important because consumer perception of packaging materials can significantly affect acceptance, especially in food-related applications. Durability recorded a moderate score (2.89), reflecting the material's ability to withstand normal handling but highlighting limitations under extended use or stress conditions. The lowest rating was observed for moisture resistance (2.54), confirming laboratory findings that the material is susceptible to water absorption. Overall acceptability (3.05) indicates that the materials are generally well-received, particularly for dry food packaging. These results suggest that while improvements are needed, especially in moisture resistance, the developed materials have strong potential for real-world application.

Table 3: Multiple Regression Results

Variable	Beta (β)	Std. Error	t-value	p-value
Tensile Strength	0.41	0.102	4.02	0.000
Water Resistance	0.36	0.095	3.79	0.001
Thickness	0.18	0.081	2.22	0.029
Constant	—	—	—	—

$R^2 = 0.63$

The regression results in Table 3 reveal that material properties significantly influence user acceptance of biodegradable packaging. Tensile strength emerged as the most influential predictor ($\beta = 0.41$), indicating that users prioritize mechanical strength when evaluating packaging materials. This aligns with practical expectations, as packaging must withstand handling and transportation. Water resistance also shows a strong positive effect ($\beta = 0.36$), reinforcing its importance as a critical performance factor. The relatively high coefficient confirms that improving moisture resistance could significantly enhance adoption rates. Thickness has a smaller but statistically significant effect ($\beta = 0.18$), suggesting that while important, it is less critical than strength and water resistance. The model explains 63% of the variation in user acceptance ($R^2 = 0.63$), indicating strong explanatory power and confirming the relevance of the selected variables.

Table 4: Structural Path Results

Path	Beta (β)	t-value	p-value	Decision
MQ → FP	0.62	7.11	0.000	Supported
FP → UA	0.58	6.87	0.000	Supported
MQ → UA	0.29	3.45	0.001	Supported

R^2 (UA) = 0.68

The SEM results confirm that Material Quality (MQ) significantly influences Functional Performance (FP) (β = 0.62), indicating that improvements in material composition directly enhance performance characteristics such as strength and resistance. Functional Performance, in turn, has a strong effect on User Acceptance (UA) (β = 0.58), highlighting that performance attributes are key drivers of adoption. The direct effect of MQ on UA (β = 0.29) suggests that users also respond to perceived material quality beyond measurable performance. The R^2 value of 0.68 indicates that the model explains a substantial proportion of variance in user acceptance, confirming the robustness of the framework. These findings support the argument that both material engineering and user perception are critical for successful adoption of biodegradable packaging.

Table 5: Independent Sample t-test

Variable	Oyo Mean	Ondo Mean	t-value	p-value
Acceptance	3.18	2.92	2.87	0.006
Durability	2.98	2.80	2.14	0.035

The results indicate that users in Oyo State reported slightly higher acceptance and durability perceptions compared to Ondo State. This difference may be attributed to variations in environmental conditions, exposure to innovation, and user expectations. The statistically significant differences highlight the importance of contextual factors in technology adoption and suggest that localized adaptation strategies may be required for wider implementation.

Qualitative findings reveal that vendors appreciate the environmental benefits of the materials and express willingness to adopt them if durability and water resistance are improved. Many respondents highlighted the potential for cost savings if materials are locally produced. However, concerns were raised regarding performance under humid conditions and the need for improved finishing. These insights complement the quantitative findings and emphasize areas for further improvement. The findings demonstrate that biodegradable packaging from plantain peels and corn husks is technically feasible and socially acceptable, particularly for dry food applications. While the materials exhibit strong environmental advantages, performance limitations especially moisture resistance remain key challenges. The results highlight the importance of integrating material science innovation with user-centered design and field validation. They also underscore the potential of agro-waste-based packaging to contribute to circular economy practices and sustainable development in Nigeria.

5.0 Conclusion and Recommendations

This study successfully developed and field-tested biodegradable packaging materials derived from plantain peels and corn husks, demonstrating their technical feasibility and practical relevance within the Nigerian context. The laboratory results confirm that the biofilms possess acceptable physicochemical and mechanical properties, including moderate tensile strength, adequate thickness, and excellent biodegradability within 21–28 days. These characteristics position the materials as viable alternatives to conventional plastics, particularly for light-duty and dry food packaging applications. The field evaluation further reveals that the developed materials are generally acceptable to users, with high ratings for ease of use and appearance, and moderate acceptance overall. However, limitations related to moisture resistance and flexibility were identified, indicating the need for further optimization. The statistical analyses establish that material properties especially tensile strength and water resistance are key determinants of user acceptance, while the structural model confirms that functional performance mediates the relationship between material quality and adoption. Importantly, the study bridges the gap between laboratory-scale innovation and real-world application by integrating material development with field validation and user feedback. It demonstrates that agro-waste resources, which are often discarded, can be transformed into value-added, environmentally sustainable products. This aligns with circular bioeconomy principles and contributes to reducing plastic pollution, promoting sustainable consumption, and supporting local innovation. The study provides strong empirical evidence that biodegradable packaging from locally available agricultural residues can play a significant role in addressing Nigeria's plastic waste challenges while creating opportunities for entrepreneurship and sustainable industrial development.

Based on the findings of this study, the following recommendations are proposed:

1. Government and private sector stakeholders should support the transition from laboratory-scale production to pilot-scale manufacturing, enabling commercialization and wider adoption of biodegradable packaging materials.
2. Policies and programs should be developed to encourage the collection and utilization of agricultural residues such as plantain peels and corn husks, thereby reducing waste and supporting circular economy practices.
3. Small and medium enterprises should be empowered through funding, training, and technical support to produce biodegradable packaging materials locally, creating jobs and stimulating economic growth.
4. Awareness campaigns should be conducted to educate consumers and vendors on the environmental benefits of biodegradable packaging, thereby increasing acceptance and demand.
5. Government agencies should develop and enforce policies that promote the use of biodegradable materials, including incentives for producers and restrictions on single-use plastics.
6. Given the observed regional differences, tailored interventions should be implemented to address local environmental conditions and user preferences in different states.
7. The findings should be incorporated into national strategies on waste management, environmental sustainability, and climate action, aligning with SDG 12 and related goals.

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