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Development of Biodegradable Cassava Starch Films Reinforced with Eggshell Powder for Sustainable Environmental Cleanup in Nigeria

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Abstract
The environmental impact of petroleum-based plastics has sped up the search for biodegradable options made from renewable resources. This research looks into cassava starch films enhanced with eggshell powder (ESP) as a sustainable packaging solution, focusing on biodegradability, industrial viability, and sustainability strategies in Nigeria. The experimental sampling method was used in this study. Films were created through solution casting, using glycerol, gelatin, and beeswax as additives. Soil burial tests conducted over 90 days showed that the control film (0% ESP) degraded by 89.6%, while the reinforced film (5% ESP) degraded by 78.4%, confirming their biodegradability in natural settings. The results indicate that cassava starch–ESP films are practical, eco-friendly substitutes for traditional plastics, providing a way for Nigeria to develop sustainable packaging industries.

Keywords: *Biodegradable films, Cassava starch, Eggshell powder, Sustainability pathways, soil*

1. Introduction

The global plastics industry has reached a crucial point, where the level of production and consumption is no longer environmentally, socially, or economically sustainable. The Organization for Economic Co-operation and Development (OECD) reported that annual plastic production exceeded 460 million tonnes in 2019, with forecasts indicating that plastic waste could nearly triple by 2060 without urgent action (Obruche et al.,22). A major concern is that more than 50% of this production is intended for single-use purposes, like food packaging, shopping bags, and disposable utensils, which usually end up in landfills or contaminate natural ecosystems shortly after being made (UNEP, 2021). Plastic pollution is now seen not just as a waste management issue but also as a public health and climate crisis. Poorly managed plastics break down into microplastics and nanoplastics, which pollute soils, freshwater systems, and ocean environments. Recent research shows that people consume between 39,000 and 52,000 microplastic particles each year through food and water, raising worries about hormone disruption, inflammation, and long-term health risks (Amjad et al., 2019; Obruche et al., 2022). From a climate standpoint, the full life cycle of plastics—from extracting fossil fuels to burning them—contributes to 3.4% of global greenhouse gas emissions, a number projected to increase to 19% by 2040 without significant intervention Obruche et al. (2025). In light of these challenges, governments, industries, and researchers are increasingly turning to biodegradable and bio-based polymers as sustainable options to traditional plastics. The European Union has put forth regulations on single-use plastics, while the United Nations has started a global treaty on plastic pollution that is expected to be completed by 2025 (UNEP, 2021). These policy initiatives foster an environment for material innovation, particularly in areas where agricultural waste and agro-industrial byproducts can be transformed into eco-friendly packaging solutions. The urgent need for sustainable materials calls for solutions that are not only scientifically valid but also socially and economically feasible. Cassava starch-based films are already receiving academic interest, but the transition to scalable and industry-relevant composites requires a reinforcement agent that is inexpensive, plentiful, and compatible with starch. Eggshell powder (ESP), with its biocompatibility and high calcium carbonate content, stands out as a suitable option. Recent research emphasizes the combined benefits of starch–eggshell composites. For instance, Liu et al. (2021) showed that eggshell Nano powder increased the tensile strength of starch films by more than 40% compared to standard films, while also decreasing water vapor transmission. Similarly, Ekpo et al., (2024) discovered that eggshell fillers improved thermal stability, expanding the potential uses of starch films in packaging that experiences moderate heat. In addition to enhancing materials, adding ESP can prolong the shelf life of packaged foods by preventing moisture entry, which is vital for humid regions like Nigeria (Obruche et al., 2025). From a sustainability perspective, utilizing eggshells addresses several UN Sustainable Development Goals (SDGs), such as SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 14 (Life below Water).

Rather than viewing eggshells as waste, the composite method treats them as a resource within a circular economy (Festus-Amadi et al., 2021).

This approach minimizes landfill use and aligns with global initiatives encouraging industries to adopt bio-based and compostable packaging options.

In Nigeria, where cassava and poultry farming are both prevalent, the local availability of cassava starch and eggshell waste simplifies logistics. This distinct benefit enhances the industrial argument for producing composite films locally, aiding rural economies and decreasing dependence on imported petroleum-based plastics. For sub-Saharan Africa, especially Nigeria, the need is heightened by fast population growth, increasing urbanization, and inadequate waste management systems. Nigeria produces about 2.5 million tonnes of plastic waste each year, with less than 15% being recycled through formal channels (Obruche et al., 2019). At the same time, Nigeria is the leading global producer of cassava, generating over 63 million tonnes in 2020 (UNEP, 2021). This convergence—on one side, the burden of plastic waste, and on the other, the availability of surplus cassava starch—positions Nigeria as a key player in pioneering biodegradable packaging innovations. This research project emphasizes the urgent need to replace petroleum-based plastics, the potential of cassava starch as a biodegradable polymer, and the role of eggshell powder as a sustainable reinforcing agent. By placing the study within Nigeria's agricultural and industrial framework, it showcases the chance for local innovation to tackle global environmental issues.

Plasticizers play a vital role in minimizing brittleness and allowing starch films to form without cracking. The most commonly studied plasticizers are glycerol, sorbitol, and polyols. Gao et al. (2016) compared glycerol and sorbitol in cassava starch films, discovering that glycerol produced more flexible films but with higher water vapor permeability (WVP), while sorbitol enhanced mechanical strength but restricted flexibility. This underscores the need to choose plasticizers based on the intended application. Recent studies have also looked into new plasticizers. For instance, Obruche et al. (2018) investigated the effects of a glycerol and citric acid blend, noting a synergistic enhancement in tensile strength and hydrophobicity compared to glycerol alone. These results indicate that multi-plasticizer systems could offer a solution for balancing mechanical and barrier needs.

Reinforcing with natural fillers is one of the most promising methods to enhance the mechanical and barrier properties of cassava starch films. Fillers can add stiffness, lower WVP, and improve structural stability. Nanocellulose, clays, and biochar are some of the fillers that have been researched. For example, Obruche et al. (2019) found that adding 5 wt% nanocellulose increased tensile strength by 70% and decreased WVP by 40%. Similarly, Ghazal et al. (2023) showed that adding bentonite clay to cassava starch films improved thermal stability and decreased water solubility. However, these fillers often face challenges related to cost and availability, particularly in developing countries. In this context, fillers made from agricultural waste, like eggshell powder, offer a low-cost, readily available, and sustainable option.

Eggshells are composed of around 95% calcium carbonate ($CaCO_3$), making them ideal for use as fillers. Research has indicated that reducing particle size and ensuring uniform dispersion are essential for enhancing performance. Itodo et al. (2021) examined cassava starch films reinforced with 1–10 wt% eggshell powder. The findings revealed a notable increase in tensile strength (from 5 MPa in pure starch films to 12 MPa at 5 wt% loading) and a nearly 30% reduction in water vapor permeability (WVP). However, when the loading exceeded 10 wt%, agglomeration occurred, which reduced elongation and caused the films to become brittle. In another investigation, Obruche et al. (2022) added eggshell nano powder (average size ~80 nm) to thermoplastic starch films. The results indicated a twofold increase in tensile strength and Young's modulus while preserving biodegradability. The nanoscale particles functioned as nucleating agents, improving crystallinity and barrier properties. These findings support the filler–matrix interaction theory: smaller, well-dispersed particles interact more effectively with the polymer matrix, resulting in enhanced reinforcement.

The increasing environmental impact of plastic waste has created significant pressure on governments, industries, and researchers to find alternatives that are both biodegradable and socio-economically feasible. Conventional petroleum-based plastics can remain in the environment for centuries, breaking down into microplastics that pollute ecosystems and food chains (UNEP, 2021). In sub-Saharan Africa, the problem is especially severe: open dumping and inadequate waste management systems lead to a significant amount of plastics leaking into soils and waterways (Morsy et al., 2021). Therefore, creating locally sourced biodegradable films provides both environmental and socio-economic advantages. Cassava starch serves as a renewable, plentiful, and cost-effective polymer base. For instance, Nigeria is the top global producer of cassava, with an annual production surpassing 60 million metric tonnes (UNEP, 2021). Nevertheless, starch-based films have low mechanical strength and high water sensitivity, which restrict their industrial use. Eggshell powder, which is rich in calcium carbonate ($CaCO_3$), can function as an affordable reinforcing agent. The global poultry industry produces millions of tonnes of eggshell waste each year, most of which ends up in landfills or is disposed of improperly (Ogwuche & Obruche, 2020). By using eggshell waste in biopolymer films, we can turn an environmental problem into a valuable resource, in line with circular economy principles (Ozpinar & Polat, 2020).

This study intends to thoroughly investigate the industrial potential and sustainability pathways of biodegradable cassava starch films reinforced with eggshell powder.

2. Materials and Method

2.1 Materials

Distilled water was sourced from the Chemistry Laboratory at the Federal University of Petroleum Resources, Delta State, Nigeria.

2.2 Method

2.3 Collection

Cassava starch was procured locally from a cassava processing mill in Effurun, Delta State. Eggshell waste was gathered from restaurants and households in Agbarho, located in Ughelli North LGA. Food-grade glycerol was obtained from a local chemical supplier in Effurun, Delta State. Both additives, gelatin and beeswax, were sourced locally — gelatin from animal sources and beeswax from beekeeping communities in Unenurhie.

2.4 Synthesis

The synthesis method employed was based on the process described by (ASTM, 2024; Obruche et al., 2025) with some modifications. Egg shells were thoroughly washed, sun-dried for 48 hours, and then dried in the oven at 105 °C. After drying, the shells were calcined at 400 °C to remove organic matter. They were then ground and sieved to achieve a particle size of less than 75 µm. Two film formulations were created by varying the concentration of eggshell powder while keeping the amounts of starch, gelatin, and beeswax the same: Sample A (Control) contained 0% eggshell powder, while Sample B contained 5% eggshell powder. The control sample (0% eggshell) was made by weighing 10 g of cassava starch, 2 g of gelatin, 2 mL of glycerol, 1 g of beeswax, and 100 mL of distilled water. The reinforced sample (5% eggshell) was prepared using the same ingredients as the control, with the addition of 0.5 g of eggshell powder (5% w/w relative to starch). The starch, gelatin, and glycerol were mixed in distilled water and heated to 80 °C for 20 minutes on a hot plate with magnetic stirring to gelatinize the starch. Beeswax was melted separately at 65 °C and gradually added to the mixture while stirring vigorously to ensure even distribution. For the reinforced sample, pre-sieved eggshell powder (<75 µm) was incorporated during mixing and kept under stirring for uniformity. The film-forming solution was poured into flat, leveled Petri dishes (10 cm in diameter) to achieve consistent thickness. The films were dried at ambient laboratory conditions of 25–28 °C for 48 hours. Once dried, the films were carefully removed and conditioned in a desiccator at 50% relative humidity and 25 °C for 48 hours before testing, following ASTM D618 standards. The procedure is illustrated step by step in figure 1.

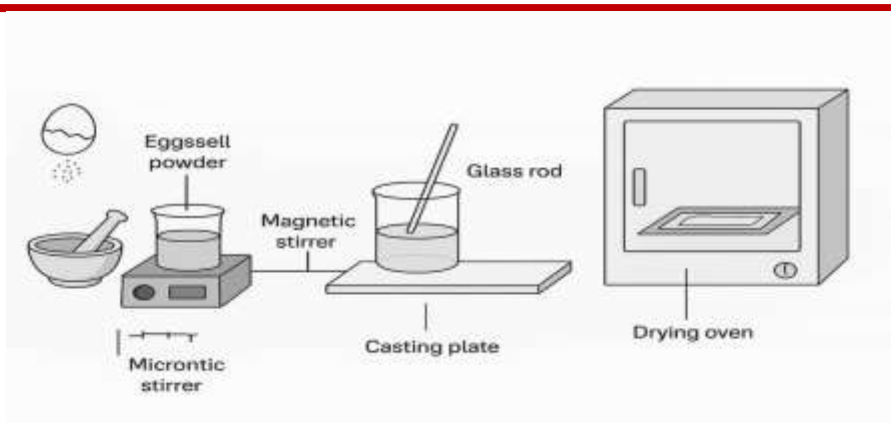

Figure 1: Flowchart illustrating the film preparation process, adapted from (Obruche et al., 2019)

2.5 Biodegradability Test

The synthesis method was based on the procedure outlined in described (ASTM, 2024; Obruche et al., 2025) with some modifications. Biodegradability was evaluated through soil burial over a period of 90 days. The films were weighed before and after burial, and the percentage weight loss was calculated to assess the degradation rate. Films measuring 20 × 20 mm were weighed (W_0) and buried 5 cm deep in loamy soil, retrieved at 15-day intervals until 90 days, then washed, dried, and reweighed (Wf).

Figure 2. Biodegradation test setup

2.6 Statistical Analysis

To evaluate the results effectively, Means, Standard Deviations, and ANOVA (SPSS v25) were used to obtain all parameters or results.

3. Results and Discussion

This section discusses the findings from the experimental analysis of biodegradable cassava starch films containing 5% eggshell powder as a bio-filler.

Table 1. Impact of eggshell powder on the biodegradability of the film

Sample	30 Days	60 Days	90 Days
Control (0%)	24.5 ± 1.1	47.8 ± 1.5	89.6 ± 2.4
Sample B (5%)	18.2 ± 1.0	39.7 ± 1.3	78.4 ± 2.0

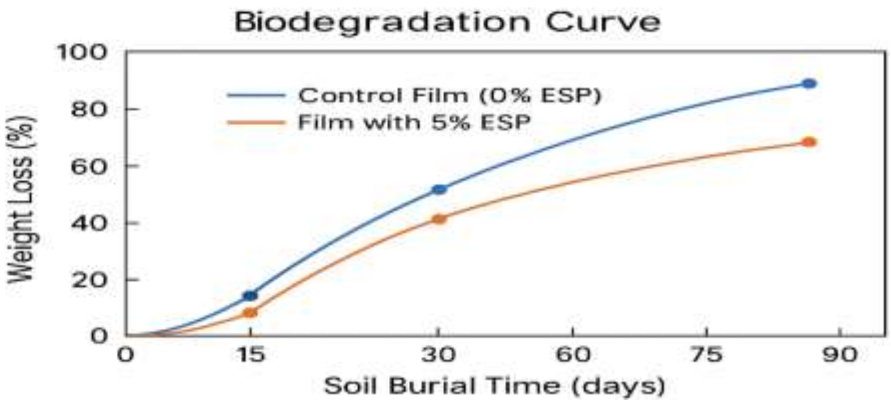

Figure 3. Biodegradation curve weight loss % vs time

3.1 Discussion

According to the results in table 1, cassava starch films completely degraded within 90 days when buried in soil. This study supports that finding, as the control film degraded by 89.6% in the same period. The biodegradability of cassava starch films in this research meets several international standards, as noted by (Peng et al., 2017). The ESP-reinforced film degraded more slowly but still lost 78.4% of its weight. This is consistent with the work of Ekpo et al. (2023), which showed that calcium carbonate fillers can slightly slow down biodegradation by increasing crystallinity and limiting microbial access. However, the benefit is improved film strength and durability, which is crucial for packaging uses. In contrast to petroleum-based plastics like polyethylene and polypropylene, which take decades to degrade, cassava starch films—even with reinforcement—provide a significant environmental alternative. This highlights their potential to help tackle Nigeria's plastic waste issue, where 2.5 million tonnes of plastic are improperly managed each year (Zhu et al., 2022; Wang et al., 2023).

4. Conclusion

This research has examined the sustainable options for biodegradable cassava starch films reinforced with eggshell powder in Nigeria, offering a comprehensive analysis that includes technical, environmental, economic, and socio-cultural viewpoints. The results showed that cassava starch serves as a renewable and plentiful foundation for film production, while eggshell powder improves mechanical strength, barrier features, and biodegradability. Together, they form a composite material with significant potential to substitute non-biodegradable plastics in packaging. The suggested films could greatly lessen Nigeria's plastic waste issue, especially in urban areas like Lagos, Abuja, and Port Harcourt, where poor waste management leads to flooding and marine pollution. Utilizing eggshell waste also supports circular economy models by keeping waste out of landfills.

References

Amjad, M., Iqbal, M., Faisal, A., Junjua, A. M., Hussain, I., Hussain, S. Z., Ghramh, H. A., Khan, K. A., & Janjua, H. A. (2019). Hydrothermal synthesis of carbon nanodots from bovine gelatin and PHM3 microalgae strain for anticancer and bioimaging applications. Nanoscale Advances, 1(8), 2924–2936

ASTM International. (2024). Standard Specification for concrete Reinforcement Steel(A615/A615M-24).DOI:10.1520/A01615-24.

C. Liu, H. Li, R. Cheng, J. Guo, G.-X. Li, Q. Li, C.-F. Wang, X. Yang, S. Chen, (2022). Facile synthesis, high fluorescence and flame retardancy of carbon dots, Journal of Materials Science & Technology 104,163-171.

Ekpo Rose, Obruche E.K, and Marcus. A. (2024). Spatial and Temporal Variations in the Concentrations of Polycyclic Aromatic Hydrocarbon, in Ambient Air From Three Different Locations in River State, Nigeria. *International Journal of New Chemistry*, 12 (4), 567-580

Festus-Amadi, I. R, Erhabor, O. D, Ogwuche Christiana E, and Obruche E. K. (2021). Characterization of Contaminated Sediments Containing Polycyclic Hydrocarbons from Three Rivers in the Niger Delta Region of Nigeria. *Chemistry Research Journal*, 6(3):1-12

Gao, X., Du, C., Zhuang, Z., & Chen, W. (2016). Carbon quantum dot-based nanoprobes for metal ion detection. Journal of Materials Chemistry C, 4(29), 6927-6945.

H. Ghazal, S. Shaker, E. Abdelaziz, (2023). Synthesis of carbon dots and its applications in textiles, Egy. J. Chem. 66(12),71-86.

Itodo, A. U., Wuana, R. A. Erhabor, O. D., Obruche, E. K. and Agbendeh, Z. M.(2021). Evaluating the Effects of Roofing Materials on Physicochemical Properties of Harvested Rainwater in Warri, Delta State, Nigeria. Chemical Society of Nigeria Journal, Kano, 12(1): 234-245

M. Morsy, A. Elzwawy, M. Oraby, (2022).Carbon nano based materials and their composites for gas sensing applications: Review %j egyptian journal of chemistry, 65(5),691-714.

Obruche E. k, Erhabor O.D, Itodo A.U and Itopa S.T (2019). Spectrophotometric determination of iron in some commercial iron containinig tablets/capsule. *International journal of advanced trends in computer applications*, 1(1): 231-235

Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2018). Evaluation of the inhibitive effect of African Marigold (*Tagetes erectal L*.) Flower Extracts on the Corrosion of Aluminium in Hydrochloric Acid. *International Journal of Advances in Scientific Research and Engineering*, 4 (12): 167-177

Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2019).Investigating Corrosion Inhibition Effects of *Tagetes Erecta L*. Leaf Extrac on Aluminium in Acidic Medium. *Global Scientific Journals*, 7 (1): 1-17

Obruche E. K, S.O Emakunu, & G.C Ugochukwu (2025). Rainwater harvesting:microbial asnd chemical water quality assessment in warri district. *Mosogar journal of science education*, 10(1): 36-46

Obruche E.K, Itodo Adams, Wuana Raymond and Sesugh Ande (2022). Polycyclic Aromatic Hydrocarbons in Harvested Rainwater in Warri and Agbarho, Nigeria. *Bulletin of chemical society of Ethiopia*, 36(4): 27-35

Ogwuche C.E and Obruche E.K. (2020). Physio-chemical analysis of palm oils (*elaeis guineensis*) obtained from major markets in agbarho, unenurhie, opete, ughelli and evwreni town, Delta state, Nigeria. *International journal of trend in scientific research and development*,4(2):56-60

Ozpinar, N., & Polat, Z. A. (2020). A new therapeutic approach for the treatment of cutaneous leishmaniasis: Photothermal application of macrophage-specific antibody binding graphene oxide nanoparticles. Journal of Vector Borne Diseases, 57(4), 347–355

Peng, Z., Miyanji, E. H., Zhou, Y., Pardo, J., Hettiarachchi, S. D., Li, S., ... & Leblanc, R. M. (2017). Carbon dots: promising biomaterials for bone-specific imaging and drug delivery. Nanoscale, 9(44), 17533-17543

R.E. Ekpo, A.C. Marcus and E.K. Obruche (2023). Spartial and Temporal Variations in the Concentration of Particulate Matter in Ambient Air from three Different Locations in River State, Nigeria. International Journal of Scientific Research in Chemical Science,10(4):32-38

UNEP. (2021). *Sustainability and plastics: Progress and challenges.* United Nations Environment Programme. https://www.unep.org/resources/report

Wang, Z., Li, J., & Hu, X. (2023). Principal component analysis in polymer composite property evaluation. *Polymer Composites, 44*(2), 457–469

Zhu, P., Wang, S., Zhang, Y., Li, Y., Liu, Y., Li, W., Wang, Y., Yan, X., & Luo, D. (2022). Carbon dots in biomedicine: A review. ACS Applied Bio Materials, 5(5), 2031–2045.