COMPARATIVE DEVELOPMENT AND EVALUATION OF BIOPLASTIC FILMS PRODUCED FROM CASSAVA PEEL STARCH (CPS) AND POTATO PEEL STARCH (PPS),

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMISTRY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE, (B.Sc.) HONOUR DEGREE IN INDUSTRIAL CHEMISTRY, DEPARTMENT OF CHEMISTRY, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.

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CERTIFICATION

This is to certify that this research project was carried out by COMFORT ONYINYE OKORO with the matriculation number PSC2105277 under the supervision of DR. I. C. ONUGUH of the DEPARTMENT OF CHEMISTRY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF BENIN, Benin City, Edo State.

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(Project Student)

DEDICATION

This project research is dedicated to God Almighty for making this project research a success and for His endless mercy upon me. I’m also dedicating this project research to my lovely parents for their unwavering love and continuous support towards me, despite all enabling me achieve this milestone.

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I sincerely express my profound gratitude to everyone who played a part in making this endeavor a success. First and foremost, my gratitude is directed towards God for giving me the mercy, guidance, and perseverance to successfully complete this project.

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ABSTRACT

The increasing environmental impact of petroleum-based plastics has intensified the global search for renewable, biodegradable alternatives. Agricultural wastes, particularly cassava and potato peels, offer promising sources of starch for sustainable bioplastic production. This study focused on the comparative development and evaluation of bioplastic films produced from cassava peel starch (CPS) and potato peel starch (PPS), using identical formulation and processing conditions. The aim was to assess how starch source influences the physicochemical, mechanical, structural, and biodegradation characteristics of the resulting films.Starch was extracted from the peels through sedimentation and drying processes, and the yield was determined gravimetrically. Bioplastic films were prepared using a standard casting method. The films were characterized for tensile strength, elongation at break, thickness, water absorption, solubility, and biodegradability. Structural and morphological properties were examined through visual observation and scanning electron microscopy (SEM). The results revealed that cassava peel produced a higher starch yield (18.6%) compared to potato peel (14.9%), confirming its superior extraction efficiency. CPS films exhibited greater tensile strength (4.85 MPa) and Young's modulus (62 MPa), indicating stronger and more rigid films, while PPS films displayed higher elongation at break (32%), signifying greater flexibility. SEM analysis showed smoother and more homogeneous surfaces in CPS films, whereas PPS films exhibited minor surface irregularities. Both films demonstrated good biodegradability under soil burial, with PPS degrading slightly faster due to its higher hydrophilicity. Overall, the findings establish cassava and potato peel starches as viable raw materials for biodegradable film production, promoting waste valorization and environmental sustainability. The higher yield and superior mechanical integrity of cassava peel starch films suggest greater industrial potential, particularly for eco-friendly packaging applications.

CHAPTER ONE

1.1 INTRODUCTION

The global reliance on conventional petroleum-based plastics has resulted in major environmental challenges, including persistent waste accumulation, generation of micro-plastics, and adverse ecological and human health impacts (Onovo et al., 2022). In response, bioplastics derived from renewable biomass and designed for biodegradation have gained considerable attention as sustainable alternatives (Peydayesh et al., 2021). Among bio-based polymers, starch is one of the most abundant polysaccharides available from agro-food residues, offering potential in the manufacture of films and packaging materials (Silveira et al., 2025). The conversion of agricultural waste into value-added bioplastic materials aligns with circular economy principles, waste valorization strategies and efforts to reduce dependence on non-renewable resources.

Starch-based films typically offer biodegradability, good film-forming ability, and compatibility with food contact applications. Research exploring films from starch extracted from food and agro-by-products has shown promising results. For example, a study on starch extracted from cassava waste prepared active films with antimicrobial properties and established their suitability for packaging applications (Silveira et al., 2025). Similarly, starch derived from potato peels has been used to fabricate edible films, demonstrating credible mechanical performance and biodegradation profiles (Motsa et al., 2022). Moreover, a comparative investigation into potato- and cassava-derived starch films highlighted both sources as viable for packaging, with physical and thermal properties approaching those of conventional low-density polyethylene (LDPE).

Utilizing cassava peel and potato peel residues offers multiple advantages. First, these agro-wastes are abundant in many tropical and subtropical regions, often under-utilized and presenting disposal challenges. Second, their starch content can be tapped for biopolymer production, thus turning waste streams into raw materials. For instance, potato peel starch has been shown to produce films with fairly good mechanical and barrier properties (Motsa et al., 2022). Meanwhile, cassava residue starch has been used successfully for film fabrication though with noted challenges in hydrophilicity and moisture sensitivity (Silveira et al., 2025).

However, although separate studies exist for cassava-based and potato-based bioplastic films, direct comparative analysis of both waste-derived starch film systems remains limited. Differences in starch structure (amylose/amylopectin ratio), residue composition, film-forming behaviour and resultant properties merit systematic investigation to identify which source may offer superior performance for film applications, under what formulation conditions, and how their biodegradability compares. Such comparative work is particularly relevant in regions where both cassava and potato production and processing generate substantial peel waste, including countries like Nigeria.

1.1.1 BACKGROUND OF THE STUDY

Plastics are used in a wide range of applications, including domestic, industrial, and commercial uses. However, as the world's population continues to increase, the demand for plastics also rises. Plastics are inexpensive, light-weight, and durable; thus, over 460 million metric tons of plastic are produced annually. Global plastic production is expected to reach a projected value of 1.1 billion metric tons by 2050.

Synthetic plastics, derived from petrochemical resources, are highly durable, leading to their persistence in the environment for hundred of years. This durability, coupled with their widespread use in packaging and other industries, has resulted in significant pollution and harmful ecological effects (Gilani *et al*.,2023). Bioplastics derived from renewable biomass and designed for biodegradation have gained considerable attention as sustainable alternatives (Peydayesh *et al*., 2021). Among bio-based polymers, starch is one of the most abundant polysaccharides available from agro-food residues, offering potential in the manufacture of films and packaging materials (Silveira *et al*., 2025). The conversion of agricultural waste into value-added bioplastic materials aligns with circular economy principles, waste valorization strategies and efforts to reduce dependence on non-renewable resources.

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1.1.2 STATEMENT OF THE PROBLEM

While petroleum-based plastics continue to dominate packaging and film applications due to their low cost, high performance, and established processing infrastructure, their environmental legacy is significant: resistance to degradation, accumulation in landfills and oceans, and contribution to micro-plastic pollution (Onovo *et al*., 2022). Bioplastics offer promise, yet many commercial bioplastics still rely on dedicated crops (e.g., corn, sugarcane) and may compete with food production or lack waste-valorization credentials. Waste-derived starch-based films therefore present a more sustainable route, though they face technical challenges: high hydrophilicity, poor moisture resistance, brittleness, variability in raw material, and sometimes sub-par mechanical performance compared to synthetic plastics (Silveira *et al*., 2025).

Specifically, in the context of starch films from agro-waste, several problems remain unresolved:

- Inconsistent film performance due to variability in waste feedstock (e.g., peel composition, starch yield, impurities).
- Limited data on how different waste starch sources (cassava peel vs. potato peel) compare under identical processing and formulation conditions.
- Inadequate understanding of how formulation parameters (plasticizer content, reinforcement, film casting methods) affect mechanical, barrier, thermal and biodegradability performance of each starch source.
- Insufficient biodegradation benchmarking of waste-derived starch films in realistic environmental conditions (soil burial, composting) and how film source influences degradation behaviour.
- Lack of localized research in regions generating large peel waste volumes (such as Nigeria) that integrates both waste valorization and film fabrication, with a view toward practical, low-cost production.

In summary, although separate studies show promise for cassava-peel starch films and potato-peel starch films, the absence of a direct comparative study under consistent conditions limits informed selection of feedstock and film formulation strategy. For waste-rich economies, this gap reduces the potential for scaling up bioplastic film production from agro-residues. Therefore, there is a need for research that directly compares film performance and biodegradation of cassava peel-derived starch films versus potato peel-derived starch films, under the same controlled experimental protocol. Such comparative insight will help identify which waste stream yields better film properties, suitability for packaging or other film applications, and whether their environmental end-of-life behaviour differs significantly.

1.1.3 SIGNIFICANCE OF THE STUDY

The growing environmental challenges associated with the accumulation of non-biodegradable plastics have intensified the global search for sustainable alternatives derived from renewable and biodegradable materials. This study holds significant relevance in addressing these issues by exploring cassava peel starch (CPS) and potato peel starch (PPS)—two abundant agricultural by-products—as potential raw materials for the production of eco-friendly bioplastic films.

From an environmental perspective, the research promotes the valorization of agro-wastes, converting peels that are often discarded or left to rot into valuable industrial feedstocks. This approach not only mitigates environmental pollution from synthetic plastic waste but also contributes to effective waste management and supports circular bioeconomy principles. By utilizing cassava and potato peels, the study encourages resource efficiency and sustainable waste-to-wealth conversion, aligning with global sustainable development goals (SDGs 12 and 13).

From a scientific standpoint, the comparative analysis of cassava and potato peel starches will deepen understanding of how the biochemical composition of starch—particularly amylose and amylopectin ratios—influences film-forming, mechanical, and degradation behaviors. Such insights are vital for tailoring starch-based materials with desired properties for specific applications, thereby expanding the knowledge base on biopolymer science and green materials.

From an industrial and economic viewpoint, this research supports the development of low-cost, locally sourced bioplastics suitable for small- and medium-scale enterprises in developing economies. Cassava and potato are widely cultivated in many tropical regions, including Nigeria, where their peels are generated in large quantities but remain underutilized. Transforming these wastes into valuable bioplastics could generate new economic opportunities, reduce dependence on imported polymers, and promote sustainable local industries.

Ultimately, this study contributes to the global effort to reduce plastic pollution, enhance environmental sustainability, and foster innovation in biodegradable material development. The findings are expected to serve as a foundation for future studies involving reinforcement agents, nano-fillers, or polymer blending aimed at improving the mechanical and barrier performance of starch-based bioplastics.

1.1.4 SCOPE OF WORK

The scope of characterization covered essential physical, mechanical, thermal, structural, and biodegradation properties. Specifically, the films were analyzed for parameters such as thickness, density, moisture content, water solubility, tensile strength, elongation at break, and thermal stability using standard laboratory methods. Structural and morphological analyses were conducted using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), while biodegradability was assessed under soil burial conditions over a specified period.

1.1.5 LIMITATIONS OF STUDY

The following limitations were acknowledged:

1. Reinforcing agents and nano-fillers such as cellulose fibers, chitosan, or zinc oxide nanoparticles were not incorporated, although these could potentially enhance mechanical and barrier properties.
2. Blending with other biopolymers (e.g., PLA, PVA, or CMC) was not explored, as the study focused solely on pure starch-based matrices.

Despite these constraints, the findings from this research provide valuable baseline data for future optimization of agro-waste-derived bioplastics and demonstrate the potential of cassava and potato peels as sustainable raw materials for eco-friendly plastic alternatives.

1.1.6 AIMS AND OBJECTIVES

The primary aim of this research is to produce, characterize, and compare bioplastic films derived from cassava peel starch and potato peel starch using a standardized formulation and processing method. The study seeks to determine how the starch source influences the physicochemical, mechanical, thermal, and biodegradation properties of the resulting films. It will also determine which agro-waste starch source exhibits greater potential for sustainable and high-performance bioplastic film development. Ultimately, this work aims to establish the potential of cassava and potato peel wastes as sustainable raw materials for the fabrication of biodegradable plastics that could replace petroleum-based materials in packaging and related applications.

To achieve the stated aim, the specific objectives of this research are to:

1. Extract starch from cassava peels and potato peels using the wet extraction method and compare their percentage yield.
2. Synthesize bioplastic films from the extracted starches using a uniform formulation containing distilled water, glycerol, and vinegar as the plasticizer and catalyst.
3. Characterize the physical and mechanical properties (such as thickness, density, tensile strength, and elongation at break) of the cassava peel starch (CPS) and potato peel starch (PPS) bioplastic films.
4. Examine the structural and morphological features of the films using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM).
5. Assess the biodegradability of the fabricated bioplastic films under soil burial conditions.
6. Compare and interpret the results to identify which starch source (cassava or potato peel) yields films with superior performance characteristics suitable for sustainable material applications.

1.1.7 Definition of Key Terms

- Bioplastic: A plastic material derived wholly or partly from renewable biological sources (such as starch) and/or designed to be biodegradable.

- Starch: A carbohydrate consisting of amylose and amylopectin, found in many plants and used as a biopolymer precursor for films.
- Cassava peel starch: Starch extracted from the waste peel of the cassava tuber (Cassava).
- Potato peel starch: Starch extracted from the waste peel of the potato tuber (Potato).
- Film-casting: A method of preparing polymer films by pouring a film-forming solution onto a substrate and drying to form a film.
- Water vapor permeability (WVP): A measure of the rate at which water vapor passes through a film under standard conditions, indicative of its barrier performance.
- Soil burial test: A biodegradation assessment method in which a material is buried in soil under controlled conditions and its weight loss or physical changes are measured over time.

1.2 LITERATURE REVIEW

1.2.1 Overview of Plastics and Environmental impacts

1.2.1.1 Evolution and Growth of Synthetic Plastics

The industrial production of synthetic plastics began in the early 20th century, following the invention of Bakelite in 1907. Since then, plastics have become indispensable materials because of their low cost, light weight, durability, and moldability into diverse forms (Andrady & Neal, 2009). Their versatility has enabled widespread use in packaging, construction, textiles, medical devices, automotive parts, and electronics. Global plastic production has grown exponentially—from approximately 2 million tonnes in 1950 to about 435 million tonnes in 2020 (Organisation for Economic Co-operation and Development [OECD], 2022). Packaging alone accounts for about 36–44 percent of total plastic consumption, underscoring the dominance of single-use items in the modern economy (Statista, 2024).

However, this tremendous growth follows a largely linear "take-make-dispose" production model, in which plastics are manufactured, briefly used, and then discarded (Geyer *et al*., 2017). Unlike natural materials, most synthetic polymers are highly resistant to degradation, leading to the long-term accumulation of plastic waste in landfills and natural environments. This persistence has made plastics one of the most pressing environmental challenges of the 21st century.

1.2.1.2 Environmental Impacts of Conventional Plastics

a) Solid Waste Accumulation and Ecosystem Pollution

The United Nations Environment Programme (UNEP, 2023a) estimates that more than 9.2 billion tonnes of plastic have been produced since the 1950s, of which about 7 billion tonnes have become waste. Only 9 percent has been recycled, 19 percent incinerated, and the remaining 72 percent disposed of in landfills or leaked into terrestrial and aquatic ecosystems (OECD, 2022). In 2020 alone, roughly 52 million tonnes of mismanaged plastic waste entered the environment through open dumping, burning, or runoff into rivers and oceans (Jaynes, 2025). Plastics constitute around 85 percent of marine litter by mass, threatening aquatic biodiversity and the safety of food webs (United Nations, 2023).

Once released into the environment, plastics undergo physical fragmentation to form microplastics (< 5 mm) and Nano plastics (< 1 µm), which persist in soil, water, and living organisms (Andrady, 2011). These particles have been detected in marine animals, agricultural soils, drinking water, and even human blood and placenta samples (Leslie et al., 2022). The infiltration of microplastics into food chains raises concerns over potential bioaccumulation and human health effects, including inflammation and endocrine disruption.

b) Greenhouse Gas Emissions and Fossil Resource Depletion

Plastic production relies heavily on fossil fuels—about 99 percent of current plastics originate from petroleum or natural gas feedstocks (UNEP, 2023b). Energy-intensive polymerization and processing stages emit substantial greenhouse gases (GHGs). In 2019, the global plastic lifecycle emitted approximately 1.8 billion tonnes of CO_2 equivalents, representing 3.4 percent of total global GHG emissions (OECD, 2022). If current production and consumption trends continue, the plastic industry could account for up to 20 percent of global oil consumption and 5 to 10 percent of GHG emissions by the year 2050 (Zheng & Suh, 2019). Beyond carbon emissions, the extraction of petroleum feedstocks depletes finite natural resources and contributes to air, soil, and water contamination.

c) Inefficient Waste Management and Low Recycling Rates

Despite decades of advocacy for recycling, global plastic recycling remains strikingly low. According to the OECD (2022), only about 9 percent of post-consumer plastic waste is recycled, 19 percent is incinerated for energy recovery, and more than half is landfilled. The remainder leaks into the environment through poor collection and disposal infrastructure. Developing countries, especially in Sub-Saharan Africa and South Asia, often rely on informal waste pickers, open dumping, and open burning, resulting in uncontrolled pollution and greenhouse-gas emissions (Hopewell *et al*., 2009).

The first global inventory of plastic-pollution leakage reported that uncollected municipal solid waste from over 1.2 billion people significantly contributes to the global burden of mismanaged plastics (SOCI, 2024). In such regions, recycling is hindered by lack of sorting facilities, inadequate investment, and contamination of recyclable materials.

d) Chemical and Health Implications

Plastics are rarely pure polymers; they contain additives such as stabilizers, flame retardants, colorants, and plasticizers, many of which are persistent and potentially toxic (UNEP, 2023c). For instance, bisphenol A (BPA), phthalates, and brominated flame retardants are known endocrine disruptors and have been linked to reproductive and developmental disorders (Rochman et al., 2013). During the lifecycle of plastics—from production to disposal—these chemicals can leach into air, water, and food, posing chronic exposure risks. Moreover, the open burning of plastic waste, which is common in regions without waste-collection services, releases hazardous compounds such as dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs) (Singh & Gupta, 2016). These emissions degrade air quality and contribute to respiratory diseases and environmental toxicity.

1.2.2 Plastic Waste Management Challenges in Developing Countries

In many low- and middle-income countries, including Nigeria, waste management infrastructure remains inadequate to handle the growing volume of plastic waste. Poor collection systems, open dumping, and uncontrolled burning are widespread due to limited funding, weak policy enforcement, and lack of public awareness (Ojewumi *et al*., 2022). Informal recycling networks often focus on high-value plastics, leaving low-density films and multilayer packaging uncollected (Nkwachukwu *et al*., 2013).

Nigeria, for example, generates more than 2.5 million tonnes of plastic waste annually, with less than 15 percent effectively recycled (Adewuyi *et al*., 2021). Much of this waste finds its way into waterways and coastal zones, aggravating flooding and environmental degradation. Similar challenges exist across Sub-Saharan Africa, Southeast Asia, and Latin America, where infrastructure gaps hinder the achievement of circular economy goals (World Bank, 2022).

Consequently, innovative solutions that promote waste valorization, resource recovery, and sustainable material substitution have become critical. The use of agricultural residues—such as cassava and potato peels—as feedstocks for bioplastics offers an attractive, low-cost strategy for both waste reduction and local economic empowerment.

1.2.3 Rationale for Bioplastic Development

The environmental and health consequences of conventional plastics have motivated the development of bioplastics, defined as polymers that are bio-based, biodegradable, or both (European Bioplastics, 2024). These materials can be derived from renewable biomass such as starch, cellulose, proteins, or lipids and are designed to degrade through microbial action under appropriate environmental conditions. Bioplastics can significantly reduce fossil-resource dependence, carbon footprint, and waste accumulation if produced sustainably and integrated into waste-management systems (Haider *et al*., 2019).

Particularly promising are starch-based bioplastics, which exploit the abundance and low cost of starch from agro-wastes such as cassava and potato peels. Utilizing such residues aligns with circular-economy principles—transforming waste into value-added materials, reducing landfill burden, and promoting sustainable rural economies (Silveira *et al*., 2025). For developing regions with high agricultural output, starch-derived bioplastics offer a locally accessible and environmentally responsible alternative to petro-based plastics.

In summary, plastics have become both a technological triumph and an ecological crisis. Their extensive use in modern society is offset by serious environmental, health, and waste-management challenges stemming from their persistence, chemical composition, and inadequate end-of-life systems. The low global recycling rate and the projected rise in production intensify the urgency to develop biodegradable, renewable substitutes. Bioplastics—particularly those made from waste-derived starch—represent a promising pathway toward sustainable materials that reduce dependence on fossil resources, enhance waste valorization, and mitigate pollution. The following sections therefore explore the concept, classification, and properties of bioplastics, with an emphasis on starch as a renewable biopolymer and on cassava and potato peels as comparative feedstocks.

1.2.4 WORLD OF BIOPLASTICS

1.2.4.1 Concept of Bioplastics

Bioplastics refer broadly to polymeric materials that are either bio-based, biodegradable, or both. According to the European Bioplastics Association (EUBP), bioplastics encompass three main categories: (i) bio-based and biodegradable (e.g., polylactic acid and starch blends), (ii) bio-based but non-biodegradable (e.g., bio-polyethylene), and (iii) fossil-based but biodegradable (e.g., polybutylene adipate terephthalate) (EUBP, 2023). The term thus describes origin and end-of-life behavior rather than a single chemical class.

The emergence of bioplastics was primarily motivated by the need to replace petroleum-based polymers with materials sourced from renewable resources. These renewable feedstocks include starch, cellulose, proteins, lipids, and microbial polyesters derived from plants, animals, or microorganisms (Shen *et al.*, 2020). Unlike synthetic polymers that persist for centuries, many bioplastics can undergo microbial degradation into water, carbon dioxide, and biomass under appropriate conditions (Emadian *et al.*, 2017).

Bioplastics can be processed using conventional polymer manufacturing techniques such as extrusion, compression molding, and casting, making them compatible with existing production infrastructure (Avérous & Pollet, 2012). Their biodegradability and partial or complete renewability make them strong candidates for sustainable materials, particularly in packaging, agriculture, and biomedical applications.

1.2.4.2 Classification of Bioplastics

a. Based on Source Material

Bioplastics can be classified according to the source of raw materials used in their synthesis:

1. Natural polymer-based bioplastics: Derived directly from naturally occurring macromolecules such as starch, cellulose, chitosan, alginate, and proteins. These materials are generally biodegradable and renewable (Avérous & Pollet, 2012).
2. Microbially produced bioplastics: These are polyesters synthesized by microorganisms, including polyhydroxyalkanoates (PHAs) and polyhydroxybutyrate (PHB). They are fully biodegradable and possess good mechanical strength (Raza *et al.*, 2022).
3. Chemically synthesized bio-based plastics: Produced from monomers obtained from renewable resources through fermentation or chemical transformation, e.g., polylactic acid (PLA) derived from fermented sugars (Shen *et al.*, 2020).

b. Based on Biodegradability

Another major classification divides bioplastics according to their ability to degrade in natural environments:

1. Biodegradable bioplastics: Materials that can be decomposed by microorganisms into simple compounds like carbon dioxide, methane, and water. Examples include PLA, PHB, polycaprolactone (PCL), and starch-based polymers (Emadian *et al*., 2017).
2. Non-biodegradable bioplastics: Bio-based polymers that do not degrade easily under natural conditions, such as bio-PE, bio-PET, and bio-PA. While derived from renewable resources, they share similar degradation characteristics with conventional plastics (European Bioplastics, 2023).

c. Based on Synthesis Pathway

Bioplastics can also be grouped based on their synthesis mechanism:

- Direct extraction from biomass: e.g., starch, cellulose, proteins.
- Biosynthesis by microorganisms: e.g., PHAs accumulated by bacterial fermentation.
- Chemical synthesis using bio-derived monomers: e.g., PLA obtained from lactic acid polymerization.

This classification is critical in understanding performance, cost, biodegradation rate, and potential applications of various bioplastics (Raza *et al*., 2022).

1.2.4.3 Advantages of Bioplastics

Bioplastics offer multiple environmental and socio-economic benefits over conventional plastics:

- Renewable feedstocks: They utilize agricultural crops or residues, reducing reliance on finite fossil fuels (Emadian *et al.,* 2017).
- Biodegradability and compostability: Certain bioplastics degrade under natural or industrial composting conditions, minimizing waste persistence.
- Reduced carbon footprint: Bio-based plastics can lower greenhouse gas emissions throughout their life cycle (Shen *et al*., 2020).
- Waste valorization: The use of agro-industrial residues such as cassava or potato peels for starch extraction promotes circular economy principles (Oluwasina *et al*., 2017).

- Compatibility with conventional processing: Bioplastics can often be processed using existing polymer-processing equipment (Avérous & Pollet, 2012).

For developing nations with abundant agricultural waste, these advantages represent a dual opportunity for environmental sustainability and rural industrialization.

1.2.4.4 Limitations and Challenges

Despite these advantages, bioplastics face several limitations that have restricted their large-scale adoption:

- Cost and scalability: Production costs remain higher than conventional plastics due to feedstock processing and purification (Hatti-Kaul *et al*., 2020).
- Mechanical and thermal properties: Many starch-based bioplastics are brittle, have poor barrier properties, and exhibit high moisture sensitivity (Yin *et al*., 2022).
- Competition with food resources: The use of edible starch sources (corn, potato, cassava) can create food–material conflicts, though using waste peels mitigates this issue (RameshKumar *et al*., 2020).
- Standardization of biodegradation testing: Degradation rates depend on environmental conditions, requiring standardized protocols to evaluate performance (Emadian *et al*., 2017).

These challenges drive current research into reinforcement and blending techniques—for example, incorporating natural fibers, nano-fillers, or plasticizers to improve film flexibility, tensile strength, and water resistance (Sanyang *et al*., 2016).

In summary, bioplastics are innovative materials developed to address the environmental drawbacks of conventional plastics through the use of renewable and biodegradable feedstocks. Their classification based on source, biodegradability, and synthesis provides insight into their diverse chemical nature and application potential. Starch-based bioplastics, in particular, are promising due to the abundance, renewability, and biodegradability of starch. The utilization of cassava and potato peel starch represents a sustainable approach to converting agro-waste into valuable polymeric materials.

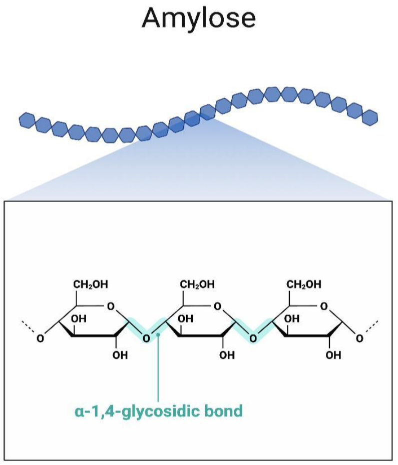
1.2.5 STARCH AS A BIOPOLYMER FOR BIOPLASTIC PRODUCTION

Starch is one of the most abundant and renewable natural polymers available for bioplastic production. It is a polysaccharide primarily composed of two glucose polymers—amylose and amylopectin—linked by α-1,4 and α-1,6 glycosidic bonds (Zullo & Iannace, 2019). The molecular arrangement and ratio of these two components determine the physicochemical behavior of starch and consequently influence its film-forming, mechanical, and barrier properties (Thakur *et al.*, 2018). Starch's natural abundance, biodegradability, film-forming ability, and thermoplastic properties make it an ideal raw material for developing eco-friendly plastics (Singh *et al.*, 2021).

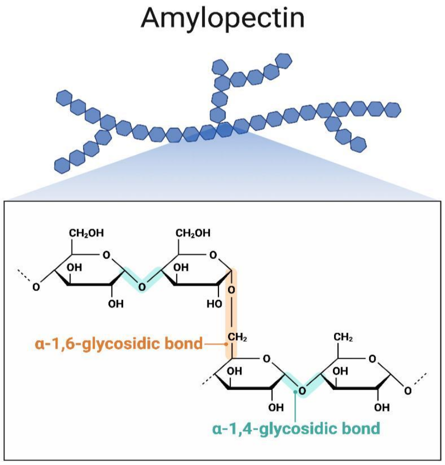
1.2.4.1 Structure and Characteristics of Starch

Starch occurs naturally as semi-crystalline granules in plant storage organs such as tubers, roots, and seeds. The granules exhibit species-specific differences in morphology, crystallinity, and size, which influence the thermal and rheological behavior during processing (Sharma & Joshi, 2017). Amylose is a mostly linear polymer with α-1,4 linkages that tends to form helical structures, while amylopectin is highly branched and contributes to the semi-crystalline nature of starch granules (Perez & Bertoft, 2019). The relative proportion of amylose to amylopectin varies among botanical sources—cassava starch typically contains 17–20% amylose, whereas potato starch contains 20–25% (Kaur *et al.*, 2020).

Fig 1.1 Diagram of starch; Amylose and Amylopectin



Amylose is composed of glucose molecules connected by α-1,4-glycosidic bonds.



Straight-chain portions of amylopectin are connected by α-1,4-glycosidic bonds, whereas the branches are connected by α-1,6-glycosidic bonds.

The molecular composition affects the gelatinization and retrogradation behavior of starch. Amylose contributes to film strength and stiffness due to its linear structure, while amylopectin enhances flexibility and transparency (Thakur *et al*., 2018). When heated in water, starch granules absorb moisture, swell, and lose their crystalline order in a process known as gelatinization. Upon cooling, the molecules realign to form a continuous film matrix, providing the foundation for bioplastic formation (Zullo & Iannace, 2019). This film-forming ability underpins its use as a base polymer in biodegradable plastic production.

1.2.4.2 Conversion of Starch to Thermoplastic Starch (TPS)

For starch to be processed like conventional plastics, it must be converted into thermoplastic starch (TPS). This is achieved by destructuring the native granules in the presence of heat, shear, and plasticizers such as glycerol, sorbitol, or citric acid (Averous, 2017). Plasticizers reduce intermolecular hydrogen bonding between starch chains, increase flexibility, and lower the glass transition temperature, thereby improving processability (Mali *et al*., 2018).

The transformation process involves breaking down the crystalline structure of starch through gelatinization and plasticization, leading to a homogeneous, amorphous material that behaves like synthetic thermoplastics under heat and pressure (Liu *et al*., 2019). TPS can be extruded, molded, or cast into films and other forms. However, pure starch-based plastics tend to exhibit high hydrophilicity, brittleness, and poor mechanical stability, which restrict their practical applications (Reddy *et al*., 2017). Consequently, researchers have explored blending starch with other biodegradable polymers such as poly(lactic acid) (PLA), polycaprolactone (PCL), or cellulose derivatives to enhance performance (Bertuzzi *et al*., 2018).

1.2.4.3 Functional Properties and Performance of Starch-Based Bioplastics

The performance of starch-based bioplastics is largely influenced by the amylose/amylopectin ratio, plasticizer type, and processing conditions. High-amylose starches tend to yield films with greater tensile strength but lower flexibility, whereas high-amylopectin starches produce softer, more elastic films (Thakur *et al*., 2018). Plasticizers such as glycerol improve elongation at break and transparency but may reduce tensile strength and water resistance (Liu *et al*., 2019). The inclusion of crosslinking agents like citric acid or reinforcement with natural fibers and nanoparticles has been shown to mitigate these drawbacks by enhancing mechanical integrity and moisture barrier properties (Khalil *et al*., 2019; Yadav *et al*., 2021).

Furthermore, starch-based bioplastics are inherently biodegradable, breaking down into carbon dioxide, water, and biomass under microbial action (Singh *et al*., 2021). Their degradation rate depends on starch composition, crystallinity, and environmental conditions. Films with higher amylose content or reinforced with hydrophobic fillers degrade more slowly due to reduced water uptake (Reddy *et al*., 2017). These attributes make starch an excellent biopolymer for sustainable packaging and other single-use plastic alternatives.

1.2.4.4 Challenges and Opportunities

Despite its promise, starch-based bioplastic faces limitations that hinder large-scale commercialization. The major challenges include moisture sensitivity, retrogradation (hardening over time), and poor thermal stability (Averous, 2017). Moreover, its mechanical strength is lower than petroleum-based polymers, making it unsuitable for high-strength applications without modification. Blending starch with other biopolymers or incorporating reinforcing agents has been widely reported as a viable strategy to address these issues (Khalil *et al*., 2019). For instance, composites made from starch and cellulose nanofibers exhibit improved tensile strength and reduced water absorption, while the addition of metal oxide nanoparticles like ZnO enhances antimicrobial and UV-shielding properties (Ogunyemi *et al*., 2021).

In addition to material enhancements, the use of agro-industrial residues such as cassava and potato peels as starch sources provides an economic and environmental advantage. These waste-based starches can substitute refined starch in bioplastic production without compromising key performance parameters (Nunes *et al*., 2020). As global concern about plastic pollution and fossil resource depletion intensifies, starch-based bioplastics—especially those derived from agricultural by-products—represent a promising pathway toward a circular bioeconomy (UN, 2022). Continued research into starch modification, reinforcement, and hybridization will be crucial to overcome existing barriers and promote industrial scalability.

1.2.6 CASSAVA PEEL AS A STARCH SOURCE

Cassava (*Manihot esculenta* Crantz) is a major root crop widely cultivated across tropical and subtropical regions. It serves as an essential carbohydrate source for millions of people and a vital raw material for various agro-industries. According to the Food and Agriculture Organization (FAO, 2023), global cassava production exceeds 280 million tonnes annually, with Nigeria, Thailand, Indonesia, and Brazil among the leading producers. During cassava processing, a considerable quantity of waste is generated in the form of peels, fiber residues, and effluents. Cassava peels, which constitute about 10–15% of the total root weight, represent a significant agro-industrial by-product that is often underutilized or improperly disposed of (Akinyemi *et al*., 2019; Ogunyemi *et al*., 2021).

Traditionally, cassava peels are discarded or burned, resulting in environmental pollution and greenhouse gas emissions. Their improper management contributes to odor nuisance, soil contamination, and methane generation during decomposition (Onyelucheya & Ogbulie, 2018). However, these peels are rich in starch and fibrous materials that can be valorized for various industrial purposes, including bioethanol, animal feed, and biodegradable plastics (Adeniyi *et al*., 2019). The starch content of cassava peels has been reported to range from 30% to 45% on a dry weight basis, depending on the cassava variety, processing conditions, and maturity stage (Ogunyemi *et al*., 2021). This relatively high starch yield underscores the potential of cassava peels as a sustainable alternative source of industrial starch.

1.2.6.1 Composition and Properties of Cassava Peel Starch

Cassava peel starch exhibits physicochemical properties comparable to those of conventional cassava root starch, though with some variations in granule morphology, amylose/amylopectin ratio, and gelatinization characteristics (Akinyemi *et al*., 2019). Cassava peel starch granules are typically oval to irregular in shape and range from 5 to 25 µm in diameter (Kaur *et al*., 2020). The amylose content of cassava peel starch is usually between 17% and 22%, which influences its gelatinization temperature and retrogradation behavior (Zainuddin *et al*., 2021). The high amylopectin fraction enhances flexibility and transparency in starch films, while the linear amylose component contributes to tensile strength and stiffness (Mali *et al*., 2018).

Thermal and pasting properties of cassava peel starch are also of significant interest in bioplastic fabrication. Studies have shown that cassava peel starch has a gelatinization temperature range of 64–72°C, similar to that of conventional cassava starch (Ogunyemi *et al*., 2021). Its relatively low gelatinization enthalpy facilitates processing under mild conditions, reducing energy consumption during film formation. However, its high hydrophilicity can lead to excessive moisture absorption, affecting the dimensional stability of resulting bioplastic films. Therefore, appropriate plasticization and reinforcement are necessary to enhance the mechanical and barrier properties of cassava peel-based materials (Khalil *et al*., 2019).

1.2.6.2 Extraction of Starch from Cassava Peel

The extraction of starch from cassava peel involves a sequence of physical and chemical processes designed to separate the starch granules from fibrous and proteinaceous materials. The standard procedure typically includes washing, drying, milling, sieving, and sedimentation, followed by drying of the recovered starch (Adeniyi *et al*., 2019). The efficiency of starch recovery largely depends on the particle size of the ground peel, pH of the extraction medium, and sedimentation time.

Some studies have optimized the extraction process using alkaline or enzymatic treatments to enhance starch yield and purity. For instance, Ogunyemi *et al*. (2021) reported that mild sodium hydroxide treatment (0.1 M NaOH) improved the removal of impurities and produced starch with superior whiteness and gelatinization properties. Similarly, Akinyemi *et al*. (2019) demonstrated that enzymatic extraction using α-amylase resulted in a higher starch recovery rate and reduced cyanogenic glycoside content, making the starch safer for handling and application. The extracted cassava peel starch can be converted into thermoplastic starch through blending with plasticizers such as glycerol or sorbitol, enabling film formation and molding under controlled heating conditions (Mali *et al*., 2018).

1.2.6.3 Application of Cassava Peel Starch in Bioplastic Production

Recent studies have explored cassava peel starch as a cost-effective raw material for biodegradable plastics. Nunes et al. (2020) produced bioplastic films from cassava peel starch and reported good film-forming ability, moderate tensile strength, and excellent transparency. The resulting films were found to be biodegradable within 45 days under composting conditions, demonstrating their environmental friendliness. Similarly, Ogunyemi *et al.* (2021) developed cassava peel starch-based bioplastics reinforced with sawdust and nano-ZnO and observed significant improvements in mechanical strength, water resistance, and antimicrobial activity.

The functional performance of cassava peel starch bioplastics can be tuned through chemical or physical modifications. For instance, acetylation or oxidation of starch can reduce hydrophilicity and improve compatibility with hydrophobic reinforcing agents (Khalil *et al*., 2019). Moreover, the incorporation of plasticizers such as glycerol enhances film flexibility, while crosslinking with citric acid or borax increases structural rigidity and water resistance (Thakur et al., 2018). Such modifications expand the potential applications of cassava peel starch bioplastics in food packaging, agricultural films, and disposable materials.

In comparative studies, cassava peel starch has shown slightly lower tensile strength than potato peel starch films, which is attributed to differences in phosphate ester groups and granule morphology (Mali *et al*., 2018). Nevertheless, cassava peel starch offers advantages such as higher clarity, faster biodegradation rate, and abundant availability in tropical regions, making it a highly promising starch source for sustainable polymer research and applications.

1.2.6.4 Environmental and Economic Implications

Utilizing cassava peel for starch extraction contributes significantly to waste minimization and sustainable resource management. Cassava processing industries, especially in sub-Saharan Africa, face major environmental challenges associated with peel disposal. By converting this agro-waste into valuable bioplastics, the process aligns with the circular bioeconomy concept, where waste streams are transformed into feedstocks for new materials (UN, 2022). Furthermore, cassava peel starch production requires minimal chemical inputs and lower processing energy compared to synthetic polymer synthesis, offering both environmental and economic advantages (Onyelucheya & Ogbulie, 2018).

The valorization of cassava peel for starch-based bioplastics also supports rural industrialization by creating value-added products from local agricultural residues. It promotes income generation for smallholder farmers and reduces dependence on imported raw materials for plastic manufacturing (Adeniyi *et al*., 2019). The overall environmental footprint of cassava peel starch production is significantly lower than that of conventional petrochemical plastics, as it is derived from renewable biomass and is fully biodegradable under natural conditions. Consequently, cassava peel starch serves as a critical link between sustainable agriculture, waste valorization, and green material innovation.

1.2.7 POTATO PEEL AS A STARCH SOURCE

Potatoes (*Solanum tuberosum* L.) are one of the most cultivated root crops worldwide, serving as a staple food and raw material for several industrial applications. Global potato production exceeded 374 million tonnes in 2022, with China, India, and Russia leading as top producers (FAO, 2023). During industrial processing—such as in the production of potato chips, starch, and fries—large quantities of waste are generated, comprising mainly peels, trimmings, and residual pulp. Potato peels constitute about 10–12% of the total tuber weight and are often discarded as solid waste, posing environmental management challenges (Singh *et al*., 2020). However, the high starch content of potato peel waste makes it an attractive raw material for value-added products such as bioplastics, bioethanol, and biodegradable composites (Chowdhury *et al*., 2021).

1.2.7.1 Composition and Characteristics of Potato Peel Starch

Potato peels contain significant amounts of starch, typically ranging from 35% to 50% on a dry weight basis, depending on the potato variety, maturity, and processing conditions (Chaudhary *et al*., 2020). The starch granules are generally large (15–100 µm), oval to spherical in shape, and display distinct birefringence under polarized light, indicating high crystalline structure (Singh *et al*., 2019). These granules exhibit a relatively high amylopectin content (75–80%), contributing to enhanced film flexibility and transparency in bioplastic formulations. The amylose fraction, generally between 20% and 25%, imparts film strength and structural integrity (Wang *et al*., 2021).

The physicochemical properties of potato peel starch, including gelatinization temperature, swelling power, and solubility, are comparable to those of starch extracted from the whole tuber. Its gelatinization temperature typically ranges between 58°C and 66°C, which is relatively low compared to other root starches such as cassava or yam (Adejumo *et al*., 2022). This feature is advantageous during thermoplastic starch formation since lower thermal input is required to disrupt the crystalline structure, resulting in energy-efficient processing. Moreover, potato peel starch exhibits a high water absorption capacity due to the abundance of hydroxyl groups in its polysaccharide structure, which influences its mechanical and barrier properties in bioplastic films (Singh *et al*., 2020).

1.2.7.2 Extraction Methods for Potato Peel Starch

Starch extraction from potato peel waste follows processes similar to those used for other starchy residues. The peels are first washed to remove adhering soil and debris, followed by grinding, sieving, and sedimentation to separate the starch granules from fibrous materials. The sedimented starch is then dried and milled into a fine powder (Chaudhary *et al.,* 2020). Studies have shown that enzymatic extraction using cellulase or pectinase can increase starch yield by breaking down the fibrous cell wall matrix (Chowdhury *et al*., 2021). Alkaline extraction (e.g., using NaOH solution) also improves starch purity and reduces pigment content, resulting in lighter-colored starch suitable for film formation (Adejumo *et al*., 2022).

Optimization of extraction parameters such as pH, temperature, and sedimentation time has been reported to significantly enhance starch recovery efficiency. For instance, extraction at pH 9 and 40°C for 30 minutes yielded starch with minimal impurities and improved paste stability (Wang *et al*., 2021). Furthermore, mechanical disruption techniques such as ultrasonic-assisted extraction have been shown to increase starch release from the peel matrix while reducing processing time (Singh *et al*., 2020). The resulting starch is then suitable for conversion into thermoplastic starch via blending with plasticizers like glycerol or sorbitol and subsequent thermoforming into films.

1.2.7.3 Application of Potato Peel Starch in Bioplastic Production

Potato peel starch has emerged as a valuable biopolymer source for developing biodegradable plastics. Its molecular structure, characterized by a high amylopectin content and large granule size, imparts favorable film-forming and mechanical properties (Chaudhary *et al*., 2020). Several studies have demonstrated that thermoplastic starch derived from potato peel can yield transparent, flexible, and biodegradable films comparable to those from pure potato starch. Chowdhury *et al*. (2021) fabricated bioplastics from potato peel starch blended with glycerol and observed tensile strength values between 4.8 and 6.3 MPa, with elongation at break exceeding 20%. These values are within the acceptable range for low-density packaging films.

The performance of potato peel starch-based films can be further improved through chemical and physical modifications. For example, acetylation and crosslinking treatments have been shown to reduce water absorption and improve tensile strength (Singh *et al*., 2019). Blending with natural fibers such as cellulose or lignin-rich agro-wastes enhances film rigidity and reduces permeability to moisture and oxygen (Adejumo *et al*., 2022). Additionally, reinforcing the films with nanoparticles such as nano-ZnO or TiO_2 improves thermal stability and antimicrobial activity, making them suitable for food packaging applications (Wang *et al*., 2021).

Comparatively, potato peel starch films often demonstrate higher tensile strength but lower biodegradation rates than cassava peel starch films due to the denser granule structure and higher phosphate content (Chaudhary *et al*., 2020). Nonetheless, both materials remain environmentally superior alternatives to petroleum-based plastics. Potato peel starch's versatility, abundance, and favorable film properties make it an excellent candidate for bioplastic development and comparative studies alongside other starch sources.

1.2.7.4 Environmental and Economic Considerations

Valorizing potato peel waste into starch for bioplastic production provides a dual benefit of waste reduction and renewable material development. The food processing industry generates millions of tonnes of potato peel waste annually, which, if unmanaged, can contribute to environmental pollution and greenhouse gas emissions (FAO, 2023). Utilizing this waste as a raw material for bioplastics supports circular economy principles by converting organic residues into high-value materials (Singh *et al*., 2020). The process requires relatively low energy input and utilizes simple extraction methods, making it economically feasible, especially for small and medium-sized enterprises.

From an environmental standpoint, starch-based bioplastics from potato peel are biodegradable under composting or soil burial conditions within 60–90 days (Chowdhury *et al*., 2021). Their production significantly reduces dependence on fossil-based polymers and lowers carbon emissions throughout the product life cycle. Economically, the availability of abundant raw material and low-cost processing techniques enhances the viability of potato peel starch as an industrial feedstock. The conversion of waste into marketable biodegradable materials also promotes sustainable industrialization and aligns with global sustainability goals (UN, 2022).

In conclusion, potato peel represents a promising, renewable, and underutilized starch source for bioplastic production. Its physicochemical characteristics, ease of extraction, and favorable film-forming properties make it a valuable material for sustainable polymer research. Comparative evaluation of potato and cassava peel starch-based bioplastics offers insights into optimizing their formulations for mechanical strength, flexibility, and biodegradability, thereby advancing the development of eco-friendly packaging solutions.

1.2.8 COMPARATIVE STUDIES ON CASSAVA AND POTATO PEEL STARCHES

The utilization of agro-industrial wastes such as cassava and potato peels as alternative starch sources has received significant attention in recent years due to the growing demand for sustainable, biodegradable materials. Both cassava and potato peel starches possess favorable physicochemical properties suitable for the development of thermoplastic starch-based bioplastics. However, distinct differences exist between the two in terms of starch yield, granule morphology, amylose-to-amylopectin ratio, and film-forming behavior (Mali *et al*., 2018; Chaudhary *et al*., 2020). Comparative evaluation of these starches provides valuable insights into optimizing bioplastic formulations for improved performance and sustainability.

1.2.8.1 Starch Yield and Composition

Cassava and potato peels differ in starch yield, depending on their botanical structure, processing methods, and regional varieties. Cassava peels typically contain 30–45% starch on a dry weight basis, while potato peels contain 35–50% (Adeniyi *et al*., 2019; Singh *et al*., 2020). Although potato peel generally exhibits slightly higher starch yield, cassava peel offers a more fibrous structure, contributing to better reinforcement potential when incorporated into composite films (Ogunyemi *et al*., 2021).

In terms of composition, cassava peel starch tends to have a lower amylose content (17–22%) compared to potato peel starch (20–25%) (Zainuddin *et al*., 2021; Wang *et al*., 2021). The lower amylose level in cassava starch results in films with higher flexibility and transparency, whereas the higher amylose content in potato starch enhances tensile strength and rigidity (Mali et al., 2018). Furthermore, potato peel starch contains naturally occurring phosphate ester groups that enhance paste viscosity and water-binding capacity (Chaudhary *et al*., 2020). Cassava peel starch, on the other hand, possesses a relatively neutral surface chemistry, leading to lower pasting viscosity but faster gelatinization (Akinyemi *et al*., 2019).

1.2.8.2 Morphological and Thermal Properties

Microscopic examination reveals that cassava peel starch granules are generally smaller (5–25 µm) and irregularly shaped, while potato peel starch granules are larger (15–100 µm), oval to spherical in morphology (Singh *et al*., 2019). These differences in granule structure influence the behavior of starch during gelatinization and film formation. The smaller granules of cassava starch allow for faster swelling and more uniform dispersion within polymer matrices, resulting in smoother films with good optical clarity (Ogunyemi *et al*., 2021). In contrast, the larger granules of potato starch promote higher water retention and improved film density but may reduce surface smoothness due to nonuniform granule dispersion (Chowdhury *et al*., 2021).

Thermal analysis using differential scanning calorimetry (DSC) has shown that cassava peel starch exhibits a gelatinization temperature range of 64–72°C, while potato peel starch gelatinizes at slightly lower temperatures of 58–66°C (Adejumo *et al*., 2022; Zainuddin *et al*., 2021). The lower gelatinization temperature of potato peel starch translates to lower processing energy requirements during bioplastic fabrication. However, cassava peel starch tends to have higher thermal stability after gelatinization, an advantage for applications requiring resistance to moderate heat or environmental stress (Mali *et al*., 2018).

1.2.8.3 Mechanical and Barrier Properties of Derived Films

The mechanical properties of bioplastic films produced from cassava and potato peel starches differ due to variations in starch molecular structure and granule size. Cassava peel starch-based films are often more flexible and transparent but exhibit lower tensile strength and Young's modulus compared to potato peel starch films (Nunes et al., 2020; Chowdhury et al., 2021). Conversely, potato peel starch films typically display greater rigidity and tensile strength due to their higher amylose content and phosphate crosslinks, which reinforce intermolecular bonding within the polymer matrix (Wang *et al*., 2021).

In terms of barrier properties, both starch types are hydrophilic and prone to water absorption; however, cassava peel starch films tend to exhibit slightly higher water vapor permeability (WVP) due to their less compact structure (Ogunyemi *et al*., 2021). Modification with plasticizers, such as glycerol or sorbitol, improves flexibility but increases WVP in both materials (Khalil *et al*., 2019). To overcome this limitation, crosslinking or reinforcement with nanomaterials (e.g., nano-ZnO, cellulose nanofibers) has been found effective for enhancing mechanical integrity and reducing moisture sensitivity (Adeniyi *et al*., 2019).

A comparative study by Mali et al. (2018) revealed that while potato starch films demonstrated higher tensile strength (7.8 MPa) and lower elongation at break (10%), cassava starch films exhibited lower tensile strength (5.2 MPa) but greater elongation (25%). These contrasting characteristics suggest that cassava peel starch films are more suitable for flexible packaging applications, whereas potato peel starch films are better suited for rigid or semi-rigid materials.

1.2.8.4 Biodegradability and Environmental Considerations

Both cassava and potato peel starch-based bioplastics are fully biodegradable, breaking down into carbon dioxide, water, and biomass under aerobic conditions. However, the rate and extent of biodegradation vary based on the starch source, film thickness, and environmental conditions (Singh *et al*., 2020). Cassava peel starch films generally degrade faster, within 30–45 days, due to their lower crystallinity and higher hydrophilicity (Nunes *et al*., 2020). Potato peel starch films, being denser and more crystalline, take slightly longer (45–60 days) to biodegrade completely (Chaudhary *et al*., 2020).

From an environmental perspective, utilizing cassava and potato peel wastes for bioplastic production significantly reduces organic waste accumulation, greenhouse gas emissions, and dependence on nonrenewable petroleum-based polymers (FAO, 2023). Economically, cassava peel starch offers an advantage in tropical regions such as sub-Saharan Africa, where cassava is abundant and inexpensive, while potato peel starch is more accessible in temperate regions (Ogunyemi *et al*., 2021). The integration of both sources in comparative or blended formulations enhances the versatility and sustainability of bioplastic materials, supporting circular bioeconomy initiatives (UN, 2022).

1.2.8.5 Implications for Material Design and Future Research

Comparative analysis of cassava and potato peel starches provides essential knowledge for designing high-performance bioplastics tailored to specific applications. Future research should focus on optimizing composite formulations that combine the favorable characteristics of both starches—such as the flexibility of cassava starch and the strength of potato starch—to produce hybrid films with balanced mechanical and barrier properties (Khalil *et al*., 2019). Additionally, advanced modification techniques such as graft copolymerization, crosslinking, and nanoparticle reinforcement could be explored to further enhance performance and extend application potential in packaging, biomedical, and agricultural sectors.

The continued exploration of cassava and potato peel starches not only supports waste valorization but also contributes to achieving Sustainable Development Goals related to responsible consumption and production (SDG 12) and climate action (SDG 13). Therefore, understanding the comparative behavior of these starches serves as a critical foundation for developing next-generation biodegradable materials that meet environmental and industrial needs.

1.2.9 EXTRACTION AND MODIFICATION OF STARCH FOR BIOPLASTIC PRODUCTION

The extraction and modification of starch play a pivotal role in determining the physicochemical properties and overall performance of bioplastic films derived from agro-wastes such as cassava and potato peels. Starch in its native form exhibits several limitations, including high hydrophilicity, poor mechanical strength, and limited thermal stability, which restrict its direct application in bioplastic fabrication. Therefore, appropriate extraction techniques and subsequent chemical or physical modifications are necessary to enhance its usability as a biopolymer (Oluwasina *et al*., 2022; Adeola & Aworh, 2020).

1.2.9.1 Extraction of Starch from Cassava and Potato Peels

Starch extraction involves separating the carbohydrate granules from the non-starch components such as fiber, protein, and lipids. The general process includes cleaning, size reduction, slurry preparation, sieving or filtration, sedimentation, drying, and milling (Kumar *et al*., 2020). Cassava peels are rich in starch content ranging from 40–60%, depending on the variety and processing conditions (Ezeoha & Ezenwanne, 2021). The extraction process often starts with peeling and washing to remove dirt, followed by grating or blending with water to form a homogeneous slurry. This slurry is filtered to separate fibrous material, and the filtrate is allowed to sediment. The starch-rich sediment is then washed repeatedly and dried at controlled temperatures to prevent gelatinization (Adebayo *et al*., 2021).

Potato peel starch extraction follows a similar approach. However, because potato peels contain higher levels of phenolic compounds and pigments, a bleaching or antioxidant treatment step (using sodium metabisulfite or citric acid) is sometimes included to improve starch purity and color (Shah *et al*., 2020). The extracted starch yield from potato peels can vary between 20% and 35%, depending on the efficiency of mechanical disintegration and washing cycles (Pathak *et al*., 2021). The extraction pH and temperature also influence the granule integrity, particle size, and amylose–amylopectin ratio, which in turn affect film formation and plasticization behavior in bioplastic applications (Singh *et al*., 2022).

1.2.9.2 Physical and Chemical Modification of Starch

While native starch has good film-forming ability, it exhibits brittleness and poor water resistance due to the abundance of hydroxyl groups that attract moisture. Hence, various modification techniques—physical, chemical, and enzymatic—are employed to tailor its properties for bioplastics production (Rosa *et al*., 2019). Physical modifications including thermal treatments such as annealing and heat-moisture treatment, which alter starch crystallinity and improve its mechanical performance (Nwokocha *et al*., 2021).

These methods do not involve chemical reagents and are therefore eco-friendly. Chemical modifications, on the other hand, involve introducing functional groups into the starch molecular structure through reactions such as acetylation, oxidation, hydroxypropylation, and crosslinking (Adebowale & Lawal, 2020). Acetylation, for example, replaces some hydroxyl groups with acetyl groups, reducing water sensitivity and enhancing flexibility (Gonzalez et al., 2021). Oxidized starches are used to increase film transparency and reduce retrogradation tendencies, making them suitable for packaging films (Alves *et al*., 2020). Enzymatic modification using α-amylase, pullulanase, or lipase offers a more biocompatible approach by partially hydrolyzing starch to produce specific molecular weight fractions that improve processability (Zhou *et al*., 2019).

1.2.9.3 Impact of Modification on Bioplastic Properties

Modified starches generally exhibit superior mechanical and thermal stability compared to their native counterparts. For instance, acetylated cassava peel starch-based films demonstrated higher tensile strength and reduced water absorption due to decreased intermolecular hydrogen bonding (Awoyale *et al*., 2022). Similarly, oxidized potato peel starch has been shown to enhance film transparency and tensile elongation at break (Singh *et al*., 2021). The addition of plasticizers such as glycerol or sorbitol during the gelatinization process further improves film flexibility by disrupting intermolecular hydrogen bonds between polymer chains (Ortega-Toro et al., 2017). In hybrid systems, combining modified starch with nanofillers such as zinc oxide nanoparticles, cellulose nanofibers, or sawdust fibers enhances the barrier and mechanical properties while maintaining biodegradability (Ibrahim et al., 2022).

1.2.9.4 Optimization of Starch Processing Parameters

Optimization of starch extraction and modification processes is essential to ensure consistent bioplastic quality. Critical parameters include pH, temperature, mixing time, and solvent ratio during extraction; and reagent concentration, reaction time, and temperature during modification (Kumar *et al*., 2020). For cassava peel starch, mild alkali treatment (NaOH 0.1–0.2 M) has been found effective in removing residual proteins and lignin, resulting in higher purity and film transparency (Ezeoha & Ezenwanne, 2021). For potato peel starch, pre-treatment with citric acid not only reduces discoloration but also introduces ester linkages that improve water resistance (Pathak *et al*., 2021). Optimization is often achieved through response surface methodology (RSM) or design of experiments (DoE) techniques that evaluate interactions among process variables (Shah *et al*., 2020).

In summary, starch extraction and modification are indispensable for converting cassava and potato peel waste into high-performance bioplastic materials. Efficient extraction maximizes starch yield and purity, while modification enhances functionality by addressing inherent weaknesses such as water sensitivity and brittleness. The synergy between extraction techniques, modification chemistry, and processing conditions ultimately dictates the mechanical, thermal, and biodegradation characteristics of the resulting bioplastic films.

1.2.9.5 Plasticizers and Additives in Starch-Based Bioplastic Formulation

The mechanical and functional performance of starch-based bioplastics largely depends on the formulation components incorporated during processing. Among these, plasticizers and additives play essential roles in improving flexibility, processability, barrier properties, and thermal stability. Pure starch-based films are inherently brittle and hygroscopic, resulting from strong intermolecular hydrogen bonding between hydroxyl groups in the glucose units (Ortega-Toro *et al*., 2017). This rigidity limits their use in flexible applications such as packaging, coating, or agricultural films. The incorporation of plasticizers and other functional additives reduces intermolecular interactions and modifies film microstructure, yielding materials with improved ductility, lower glass transition temperature, and enhanced usability (Lourdin *et al*., 2019; Singh *et al*., 2022).

1.2.9.6 Role of Plasticizers in Starch-Based Bioplastics

Plasticizers are low molecular weight compounds added to polymers to increase flexibility and workability by reducing intermolecular forces and increasing free volume within the polymer matrix (Sanyang *et al*., 2018). In starch-based bioplastics, common plasticizers include glycerol, sorbitol, polyethylene glycol (PEG), and citric acid, all of which interact with hydroxyl groups in starch molecules through hydrogen bonding (Alves *et al*., 2020). This interaction disrupts crystalline regions, enhances chain mobility, and leads to a softer, more elastic material. Glycerol remains the most frequently used plasticizer due to its effectiveness, availability, and compatibility with starch (Lourdin *et al*., 2019). However, excessive glycerol incorporation can increase hydrophilicity, leading to higher water absorption and reduced tensile strength (Thakur et al., 2019). Sorbitol, being less hygroscopic than glycerol, offers improved water resistance and tensile properties but may lead to brittle films if used alone. To balance performance, researchers often use binary plasticizer systems such as glycerol-sorbitol or glycerol-citric acid combinations, which optimize flexibility and moisture sensitivity (Taghizadeh *et al*., 2020).

The mechanism of plasticization can be classified as internal or external. Internal plasticization involves modification of starch through chemical derivatization (e.g., esterification with citric acid), whereas external plasticization involves physical mixing of plasticizers during film casting or extrusion (Sanyang *et al*., 2018). Both approaches aim to decrease the glass transition temperature (Tg) of starch from above 100°C to approximately 60–80°C, facilitating easier thermoplastic processing (Arrieta *et al*., 2020). Moreover, plasticization enhances film transparency and smoothness by reducing microcracks and improving homogeneity (Gonzalez *et al*., 2021).

1.2.9.7 Additives for Functional Enhancement

Apart from plasticizers, several additives are incorporated into starch-based formulations to enhance properties such as thermal stability, biodegradability, antimicrobial activity, and UV protection (Abdul Khalil *et al*., 2021). Crosslinking agents such as citric acid, borax, or glutaraldehyde are often used to improve water resistance and mechanical integrity by forming ester or ether linkages between starch chains (Rosa *et al*., 2019). Crosslinking reduces solubility and swelling by limiting polymer chain mobility and decreasing the number of hydrophilic sites. Fillers and reinforcements, including cellulose fibers, sawdust, nano-clay, and zinc oxide nanoparticles (ZnO-NPs), are added to improve tensile strength, barrier properties, and durability. For instance, nano-ZnO has been reported to enhance the tensile strength and thermal resistance of cassava starch-based films while imparting antimicrobial functionality (Ibrahim et al., 2022). Similarly, sawdust fibers and cellulose nanocrystals improve modulus and stiffness by creating interfacial hydrogen bonding with starch molecules (Awoyale *et al*., 2022).

Antioxidants such as citric acid and ascorbic acid are introduced to minimize oxidative degradation during film storage and processing (Shah *et al.*, 2020). Colourants or natural pigments can also be added to improve aesthetic appeal or provide light-blocking capability for food packaging applications (Pathak *et al.*, 2021).

Compatibilizers like maleic anhydride or stearic acid are sometimes incorporated in hybrid starch-polymer composites to improve interfacial adhesion between hydrophilic starch and hydrophobic polymer phases (Singh et al., 2021). Such compatibilization is especially relevant when blending starch with polyvinyl alcohol (PVA) or polylactic acid (PLA), resulting in bioplastics that combine biodegradability with enhanced mechanical stability (Zhou *et al.*, 2019).

1.2.9.8 Optimization of Additive Concentration

The concentration of plasticizers and additives must be optimized to achieve a balance between flexibility, mechanical strength, and water sensitivity. High plasticizer content results in excessive free volume, leading to lower tensile strength and higher elongation, whereas low plasticizer content leads to brittle films (Sanyang *et al.*, 2018). Optimum levels typically range from 20–35 wt% for glycerol and 10–25 wt% for sorbitol, depending on starch source and processing conditions (Adebowale & Lawal, 2020).

Crosslinking agent concentration also influences film solubility and stiffness. Excessive crosslinking may render the film too rigid, while insufficient crosslinking may fail to improve moisture resistance (Rosa *et al.*, 2019). For instance, cassava starch films crosslinked with 2–5% citric acid exhibited optimal mechanical and water barrier performance (Adeola & Aworh, 2020). Similarly, small additions of nano-ZnO (0.5–1.5 wt%) were sufficient to enhance both tensile strength and antimicrobial efficacy without compromising transparency (Ibrahim *et al.*, 2022).

Processing techniques such as solution casting, extrusion, and compression molding also influence additive performance. During thermal processing, plasticizers must be thermally stable to prevent evaporation or decomposition. The choice of mixing sequence and temperature affects the distribution and compatibility of additives within the starch matrix (Kumar *et al.*, 2020). Uniform dispersion is critical to avoid phase separation, especially in nanocomposite formulations (Nwokocha *et al.*, 2021).

1.2.9.9 Combined Effects on Bioplastic Properties

The combined effects of plasticizers and additives significantly influence the final film’s morphology, crystallinity, and degradation behavior. Glycerol-based films tend to show increased chain mobility, leading to reduced crystallinity and greater elongation at break, while sorbitol increases rigidity and reduces moisture uptake (Lourdin *et al*., 2019). Crosslinking and reinforcement compensate for the mechanical weaknesses introduced by plasticizers. For instance, a combination of glycerol (30%), citric acid (3%), and nano-ZnO (1%) in cassava peel starch film produced a flexible, transparent, and moderately water-resistant bioplastic suitable for food packaging (Awoyale *et al.,* 2022; Ibrahim *et al*., 2022). These synergistic formulations illustrate the importance of balancing molecular interactions among starch, plasticizers, and additives.

In summary, plasticizers and additives are indispensable in tailoring the functional performance of starch-based bioplastics. They modify starch–starch and starch–water interactions, thereby enhancing flexibility, mechanical strength, and barrier properties. The right combination of plasticizers and additives transforms inherently brittle native starch into a versatile material suitable for sustainable packaging and related applications. Understanding their roles and optimization is crucial for developing cassava and potato peel-based bioplastics with improved performance and environmental compatibility.

1.2.10 CHARACTERIZATION OF STARCH-BASED BIOPLASTIC FILMS

Characterization of starch-based bioplastic films is a critical phase in understanding the material’s structure–property relationships, performance, and suitability for specific applications. The evaluation involves physicochemical, mechanical, thermal, morphological, barrier, and biodegradation analyses, which collectively determine how processing parameters and additives affect the final product (Thakur *et al*., 2019). Since starch-based bioplastics derived from cassava and potato peels are increasingly studied as sustainable alternatives to petroleum-based plastics, comprehensive characterization provides insight into their potential for packaging, agricultural, and biomedical uses (Adeola & Aworh, 2020).

The performance of bioplastic films is influenced by several factors such as starch source, plasticizer concentration, reinforcement additives, and processing conditions. Characterization techniques thus provide essential data on molecular structure, crystallinity, surface morphology, and functional properties such as water absorption, tensile strength, elongation at break, and thermal degradation behavior (Arrieta *et al*., 2020).

1.2.10.1 Physical and Mechanical Properties

The physical and mechanical properties of starch-based bioplastics are vital indicators of their functionality. Parameters such as thickness, tensile strength, elongation at break, Young's modulus, and flexibility are routinely measured following ASTM D882 standards (Sanyang et al., 2018). Tensile strength reflects the film's resistance to breaking under tension, while elongation at break indicates ductility and flexibility.

Studies have shown that the mechanical strength of cassava peel starch films generally increases with the inclusion of crosslinkers like citric acid or reinforcement fillers such as cellulose fibers and nano-ZnO (Awoyale *et al*., 2022). Similarly, potato peel starch-based films plasticized with glycerol or sorbitol exhibit increased flexibility but lower tensile strength due to disruption of hydrogen bonds between starch chains (Singh *et al*., 2021). The choice of starch source plays a major role: cassava starch, with higher amylopectin content, tends to form more flexible films, whereas potato starch, richer in amylose, yields stronger but less extensible materials (Kumar *et al*., 2020).

Film thickness and density influence mechanical and optical properties. Thicker films tend to exhibit lower transparency but improved tensile performance (Pathak *et al*., 2021). Moisture content and solubility tests assess the hydrophilicity of the bioplastic, which is important for packaging applications. Cassava-based films usually display higher water absorption than potato-based ones due to their granular size and structural porosity (Ezeoha & Ezenwanne, 2021).

1.2.10.2 Thermal and Structural Characterization

Thermal characterization provides insights into the stability and processing behavior of bioplastic films. Techniques such as Thermogravimetric Analysis (TGA), Differential Scanning Calorimetry (DSC), and Fourier Transform Infrared Spectroscopy (FTIR) are commonly used (Gonzalez *et al*., 2021).

TGA assesses the material's weight loss with increasing temperature, revealing moisture content, plasticizer evaporation, and thermal degradation stages. Typically, starch-based bioplastics exhibit multi-stage degradation: the first below 150°C (water loss), the second between 250–350°C (starch and glycerol degradation), and the third above 400°C (carbonaceous residue formation) (Rosa *et al*., 2019). The inclusion of reinforcing fillers such as nano-ZnO or cellulose nanocrystals enhances thermal stability by restricting polymer chain mobility and delaying decomposition onset (Ibrahim *et al*., 2022).

DSC is used to identify thermal transitions such as the glass transition temperature (Tg), melting point (Tm), and crystallization behavior. Plasticization lowers Tg by increasing molecular chain mobility, while crosslinking tends to raise it (Ortega-Toro *et al*., 2017). Higher amylose content, as found in potato starch, generally leads to higher crystallinity and thermal stability compared to cassava starch (Shah *et al*., 2020).

FTIR analysis identifies chemical interactions and confirms modification or additive incorporation. Characteristic starch peaks include O–H stretching (3200–3500 cm^{-1}), C–H stretching (2800–3000 cm^{-1}), and C–O–C vibrations (1000–1200 cm^{-1}). Shifts in O–H peaks often indicate hydrogen bonding between starch and plasticizer molecules (Adebowale & Lawal, 2020).

1.2.10.3 Morphological and Barrier Properties

Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) provide morphological information about surface roughness, uniformity, and filler dispersion. Smooth, homogenous surfaces suggest good starch–plasticizer compatibility, while cracks or granule residues indicate incomplete gelatinization (Abdul Khalil *et al*., 2021). Incorporation of nano-fillers or fibers enhances surface compactness and reduces microvoids, thereby improving mechanical and barrier properties (Ibrahim *et al*., 2022).

Barrier properties, including water vapor permeability (WVP) and oxygen permeability, are critical for packaging applications. High WVP limits bioplastic usage in humid environments. Plasticizer type and concentration significantly influence permeability; for instance, glycerol tends to increase WVP due to its hydrophilic nature, while sorbitol or crosslinked systems exhibit lower permeability (Sanyang *et al*., 2018). Reinforced films with nanoclay or ZnO show lower permeability by creating a tortuous path for gas diffusion (Pathak *et al*., 2021).

Optical properties such as transparency and opacity are also assessed using UV–Vis spectrophotometry. Transparent films are desirable for food packaging, but higher opacity may be preferred for UV protection (Gonzalez *et al*., 2021). Cassava starch films generally show better transparency than potato starch films due to smaller granule size and lower amylose crystallinity (Awoyale *et al*., 2022).

1.2.10.4 Biodegradation and Environmental Assessment

One of the major advantages of starch-based bioplastics is their biodegradability under natural environmental conditions. Biodegradation tests, conducted under soil burial, composting, or microbial inoculation environments, assess weight loss, morphological changes, and CO_2 evolution over time (Rosa *et al*., 2019). Cassava and potato peel starch-based bioplastics typically degrade within 30–90 days, depending on formulation and environmental conditions (Adeola & Aworh, 2020).

The degradation process involves microbial hydrolysis of glycosidic bonds, facilitated by enzymes such as amylase and glucoamylase. Films containing plasticizers and natural reinforcements degrade faster than crosslinked or nanofiller-reinforced films due to increased hydrophilicity (Sanyang *et al*., 2018). Nonetheless, even reinforced starch-based bioplastics demonstrate complete disintegration within a few months, confirming their environmental compatibility (Ibrahim *et al*., 2022).

Life Cycle Assessment (LCA) studies further confirm that starch-based films have significantly lower carbon footprints compared to synthetic plastics like polyethylene or polypropylene (Singh *et al*., 2022). The use of agro-waste sources such as cassava and potato peels enhances sustainability by valorizing waste and reducing landfill pollution.

In summary, comprehensive characterization of starch-based bioplastic films reveals that the material’s performance strongly depends on its source, formulation, and processing method. Mechanical, thermal, morphological, and biodegradability assessments collectively determine their functionality and application potential. Films derived from cassava and potato peels exhibit promising mechanical integrity, acceptable thermal resistance, and complete biodegradability, making them viable candidates for sustainable plastic alternatives.

1.2.11 APPLICATION OF STARCH-BASED BIOPLASTICS

Starch-based bioplastics have attracted increasing global interest as sustainable alternatives to petroleum-derived plastics due to their biodegradability, renewability, and cost-effectiveness. Derived from agricultural residues such as cassava and potato peels, these materials can be engineered for diverse applications spanning packaging, agriculture, biomedical, and disposable consumer goods (Kumar *et al.*, 2021). The versatility of starch lies in its thermoplastic nature—when plasticized and processed under heat and shear, it forms flexible films and molded items suitable for short-life applications (Thakur *et al.*, 2019).

However, while starch-based bioplastics offer environmental benefits, their hydrophilicity and lower mechanical strength compared to synthetic plastics pose challenges that often necessitate blending, crosslinking, or nanofiller reinforcement to expand their industrial usability (Arrieta *et al.*, 2020). The use of cassava and potato peel starches aligns with the circular bioeconomy paradigm by transforming agro-waste into high-value materials, thereby reducing waste accumulation and supporting rural economies (Adeola & Aworh, 2020).

1.2.11.1 Packaging Applications

The packaging industry represents the most prominent sector for starch-based bioplastics. Global environmental concerns regarding single-use plastics have encouraged the development of biodegradable packaging films from renewable sources (Gonzalez *et al.*, 2021). Starch-based films, particularly those derived from cassava and potato peels, exhibit desirable attributes such as transparency, printability, and adequate tensile strength for light-duty packaging (Pathak et al., 2021).

Studies have demonstrated that cassava starch-based films, when blended with other biopolymers such as polyvinyl alcohol (PVA) or chitosan, show enhanced flexibility, water resistance, and antimicrobial activity suitable for food packaging (Singh *et al.*, 2022). For instance, cassava starch–chitosan films incorporated with essential oils have been applied in meat and fruit packaging to extend shelf life through microbial inhibition (Kumar et al., 2021). Similarly, potato peel starch films, reinforced with nanoclays or cellulose fibers, demonstrate reduced oxygen permeability and improved tensile strength—critical parameters for packaging dry food and pharmaceutical items (Rosa *et al*., 2019).

Edible films and coatings represent another innovative area. Edible starch-based coatings can protect food surfaces from moisture and gas exchange, while being safe for consumption. Cassava and potato starch-based edible coatings enriched with natural antioxidants or antimicrobials have been successfully tested for fresh-cut fruits, cheese, and bakery products (Abdul Khalil *et al*., 2021). Such applications align with global goals of minimizing synthetic packaging waste and improving food preservation in an environmentally benign manner.

1.2.11.2 Agricultural Applications

Starch-based bioplastics are increasingly utilized in agricultural systems, primarily in the form of mulch films, seed coatings, and controlled-release fertilizer carriers (Thakur *et al*., 2019). Traditional polyethylene mulch films pose severe disposal issues after use; hence, biodegradable starch-based alternatives offer eco-friendly replacements that degrade in soil, improving soil health while reducing pollution (Sanyang *et al*., 2018).

Cassava peel starch films have been developed as soil-biodegradable mulch films that decompose within 60–90 days, promoting sustainable crop cultivation (Adebowale & Lawal, 2020). Likewise, potato peel starch-based films loaded with micronutrients or biofertilizers have been explored for controlled release applications, ensuring gradual nutrient availability and enhanced plant growth (Ibrahim *et al*., 2022). The hydrophilicity and biodegradability of starch make it particularly suitable for these roles, allowing complete assimilation into the soil carbon cycle.

Moreover, starch-based hydrogels derived from cassava starch are being applied as soil conditioners and water-retaining agents in arid agricultural systems (Awoyale *et al*., 2022). Such innovations demonstrate the potential of starch-based materials not only in replacing plastics but also in enhancing agricultural productivity and resilience under changing climatic conditions

1.2.11.3 Biomedical and Other Applications

Recent advancements have extended starch-based bioplastics into biomedical, pharmaceutical, and consumer product applications. Due to their biocompatibility, non-toxicity, and biodegradability, starch-based materials are being investigated for wound dressings, drug delivery systems, and temporary medical implants (Gonzalez *et al*., 2021). Thermoplastic starch films blended with gelatin or polylactic acid (PLA) provide flexible and breathable matrices ideal for wound healing applications (Rosa *et al*., 2019).

In the pharmaceutical industry, cassava and potato starch-derived films have been explored as biodegradable capsules and film coatings for tablets. Their natural disintegration in aqueous environments ensures controlled drug release without residual toxicity (Adeola & Aworh, 2020).

Beyond biomedical uses, starch-based bioplastics have found increasing adoption in disposable consumer products such as shopping bags, cutlery, and food containers. For example, cassava starch bioplastic bags have been commercialized in several countries as eco-friendly substitutes for polyethylene bags (Thakur *et al*., 2019). Similarly, molded potato peel starch composites are being trialed in the manufacture of plates and trays for single-use catering applications (Singh *et al*., 2022).

1.2.11.4 Future Prospects

While starch-based bioplastics have achieved significant commercial progress, large-scale adoption still faces limitations related to cost, moisture sensitivity, and limited mechanical durability. Ongoing research focuses on developing starch nanocomposites, crosslinked blends, and chemical modifications to improve water resistance and thermal performance (Arrieta *et al*., 2020). Integrating cassava and potato peel starches with emerging green fillers such as lignin, cellulose nanofibers, and nano-ZnO offers promising routes for next-generation biodegradable materials (Ibrahim *et al*., 2022).

The global movement toward biodegradable packaging and plastic bans positions starch-based bioplastics as a viable, scalable solution for environmental sustainability. Cassava and potato peel starches, being abundant agro-wastes, can drive a circular bioeconomy, reduce post-harvest waste, and create rural employment while mitigating plastic pollution (Adeola & Aworh, 2020).

1.2.11.5 Research Gaps Identified

Although considerable progress has been made in developing starch-based bioplastics from renewable resources, several critical research gaps persist, particularly concerning the utilization of cassava and potato peel starches as sustainable raw materials. Most existing studies have primarily focused on starch derived from edible portions rather than agro-waste sources, resulting in limited data on starch yield optimization, film performance consistency, and industrial scalability of bioplastics from cassava and potato peels (Adeola & Aworh, 2020).

Another significant gap lies in the comparative performance evaluation of bioplastics derived from different peel starch sources under identical processing conditions. While individual studies have reported on cassava or potato peel starch separately, systematic comparative analyses involving mechanical, thermal, and biodegradation characteristics remain scarce (Awoyale *et al*., 2022). Moreover, the influence of plasticizer type, concentration, and nanofiller incorporation on the physicochemical and barrier properties of such films has not been comprehensively elucidated.

In addition, there is a dearth of information regarding the long-term stability, aging behavior, and environmental degradation mechanisms of cassava and potato peel starch-based bioplastics. Most biodegradability studies are short-term and lack correlation with real-world environmental conditions (Ibrahim *et al*., 2022). Furthermore, the economic and life cycle assessments (LCA) of using agro-waste starches for bioplastic production are underexplored, despite their relevance to sustainable commercialization.

Addressing these gaps through controlled comparative experiments, optimization of starch extraction and modification processes, and integration of reinforcement strategies will be vital to advancing the functional performance and industrial applicability of cassava and potato peel starch-based bioplastics.

CHAPTER TWO

MATERIALS AND METHODS

2.1 Materials

2.1.1 Raw Materials

The principal raw materials utilized in this research were cassava peels and potato peels, which served as the starch sources for bioplastic production. Fresh cassava (*Manihot esculenta*) and potato (*Solanum tuberosum*) peels were obtained from the sellers of the tubers at Uselu Market, Benin City Edo State Nigeria. These agro-waste materials were selected due to their high starch content, availability, and environmental disposal challenges, aligning with sustainable waste valorization goals (Adeola & Aworh, 2020).

2.1.2 Chemicals and Reagents

All chemicals and reagents used in this study were of analytical grade and they included glycerol, 5% vinegar, ethanol (for washing and starch purification), and distilled water (as solvent).

2.1.3 Equipment and Instruments

The instruments and apparatus employed in this study included:

- Digital weighing balance (accuracy ±0.001 g) for precise mass measurement of materials;
- Hot air oven for drying starch and films;
- Magnetic stirrer with heating plate for gelatinization and film-forming solution preparation;
- Petri dishes or casting trays for film casting;
- Tensile testing machine (in accordance with ASTM D882) for measuring film strength;
- FTIR spectrophotometer for functional group analysis;
- Scanning Electron Microscope (SEM) for surface morphology study

2.2 METHODOLOGY

2.2.1 Preparation of Starch from Cassava and Potato Peels

2.2.2 Overview of Starch Extraction Process

The extraction of starch from cassava and potato peels was carried out using a wet milling and sedimentation method, adapted from the procedures described by Adeola and Aworh (2020) and

Pathak *et al*. (2021). The process was designed to obtain high-purity native starch suitable for subsequent bioplastic film formulation. The methodology consisted of four main stages: pre-treatment, pulping and sieving, sedimentation and washing, and drying and pulverization.

Both cassava and potato peels were processed separately but under identical experimental conditions to ensure comparability. The extraction efficiency was determined by calculating the starch yield based on the ratio of dry starch weight to the initial dry mass of peels.

2.2.3 Pre-treatment and Pulping

Fresh peels were washed thoroughly with distilled water to remove adhering soil particles and impurities. They were then cut into smaller pieces (2–3 cm) and soaked in a dilute 0.1% sodium metabisulphite solution for 30 minutes to prevent enzymatic browning and microbial spoilage (Awoyale *et al*., 2022). After soaking, the peels were blended using a high-speed laboratory blender with a water-to-peel ratio of 2:1 (v/w) until a smooth slurry was obtained.

The resulting slurry was filtered through a muslin cloth and the filtrate collected in a sedimentation tank. The residue was rinsed several times to ensure maximum starch recovery. This pulping and sieving stage facilitates the mechanical release of starch granules from the cellular matrix of the peels (Kumar *et al*., 2021).

2.2.4 Sedimentation, Washing, and Drying

The filtrate was allowed to stand undisturbed for 12 hours to enable starch sedimentation. The supernatant was carefully decanted, and the sedimented starch was repeatedly washed with distilled water until a neutral pH was achieved, ensuring removal of residual impurities, pigments, and soluble proteins (Ibrahim *et al*., 2022).

The washed starch was oven-dried at 45–50 °C for 12 hours to prevent gelatinization and degradation. The dried starch cake was then gently ground using a mortar and pestle and passed through a 250 µm sieve to obtain fine starch powder. The samples were stored in airtight polyethylene containers in a desiccator until further use.

2.2.5 Starch Yield Determination and Characterization

The percentage yield of starch from cassava and potato peels was calculated using Equation (2.1):

$$\text{Starch yield (\%)} = \frac{Weight\ of\ dry\ \ starch\ obtained\ (g)}{Weight\ of\ fresh\ peel\ sample\ used\ (g)}\ x\ 100 \qquad (2.1)$$

2.2.6 Preparation and Fabrication of Bioplastic Films

The bioplastic films were produced using the solution casting technique, which allows controlled formation of uniform starch-based films. The procedure was carried out separately for cassava peel starch (CPS) and potato peel starch (PPS) to enable comparative evaluation. The process involved gelatinization of starch, plasticization, mixing and casting, and drying to produce flexible, uniform, and transparent films suitable for physicochemical and mechanical characterization.

2.2.7 Formulation Composition

Each batch of bioplastic film was prepared using the following composition:

- Starch (CPS or PPS): 20 g
- Distilled water: 100 mL
- Glycerol: 15 mL
- 5% Vinegar (acetic acid solution): 15 mL

All reagents used were of analytical grade.

2.2.8 Procedure

1. Dispersion: Twenty grams (20 g) of starch was dispersed in 100 mL of distilled water in a 400 mL beaker and stirred for 10 minutes to achieve uniform suspension.
2. Gelatinization: The mixture was heated gradually to 80–85 °C under continuous stirring for 20 minutes, allowing the starch granules to gelatinize and form a viscous paste.

3. Addition of Plasticizer and Acid: While maintaining temperature, 15 mL of glycerol and 15 mL of 5% vinegar were added dropwise with constant stirring. The mild acidity promoted better gelatinization and improved film smoothness. Stirring continued until a clear, homogeneous, and bubble-free solution was obtained.
4. Casting: The resulting solution was poured onto clean, leveled glass plates (90 mm diameter) and spread uniformly to form films of approximately 1 mm thickness.
5. Drying: The films were dried in a hot air oven at 40 °C for 48 hours until all moisture evaporated.

This method produced transparent, flexible, and smooth bioplastic films suitable for physicochemical, mechanical, and thermal analyses. All experimental conditions such as gelatinization temperature, plasticizer concentration, drying temperature, and conditioning time were kept constant to ensure that any observed differences in film behavior could be attributed solely to the intrinsic composition and morphology of the starch extracted from each peel source.

2.3 Physical Characterization

2.3.1 Film Thickness

Film thickness was measured using a digital micrometer (±0.01 mm) at five random locations on each film sample, and the mean value was recorded. Uniform thickness is critical for ensuring consistent mechanical and barrier properties (Sanyang *et al.*, 2018).

2.3.2 Moisture Content and Water Absorption

Moisture content was determined by drying pre-weighed film samples in a hot-air oven at 105 °C until constant weight was achieved, following the procedure of Thakur et al. (2019). The difference in weight before and after drying was used to calculate moisture percentage. Water absorption (WA) was assessed by immersing film samples in distilled water at room temperature (25 °C) for 24 hours. The films were then removed, surface water gently blotted off, and reweighed. The percentage increase in weight indicated the degree of water absorption (Adeola & Aworh, 2020).

2.3.3 Solubility and Swelling Index

Film solubility was determined by immersing dried samples in distilled water for 24 hours, followed by filtration and drying of the insoluble fraction. The swelling index (SI) was calculated as the percentage increase in weight of the wet film relative to its dry mass (Pathak *et al.*, 2021). These parameters provided insight into the films' hydrophilic nature and water sensitivity.

2.3.4 Mechanical Characterization

Mechanical performance was evaluated using a universal testing machine (UTM) in accordance with ASTM D882-12 standards. Film strips (10 mm × 100 mm) were clamped with an initial grip separation of 50 mm and tested at a crosshead speed of 5 mm/min. The tensile strength (TS), elongation at break (EAB), and Young's modulus (YM) were computed from the resulting stress–strain curves.

Tensile strength indicates the film's resistance to applied force, while elongation at break measures flexibility and extensibility. Young's modulus represents stiffness and structural rigidity (Arrieta *et al.,* 2020). The comparative analysis of CPS and PPS films provided insights into how amylose–amylopectin ratio and plasticizer concentration influence mechanical integrity.

2.4 Structural and Morphological Characterization

2.4.1 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy was performed in the range of 4000–500 cm^{-1} using a Nicolet FTIR spectrometer to identify functional groups and molecular interactions between starch, plasticizers, and additives. Characteristic peaks corresponding to –OH, C–O–C, and C=O stretching vibrations were analyzed to verify plasticization and hydrogen bonding (Gonzalez et al., 2021).

2.4.2 Scanning Electron Microscopy (SEM)

SEM micrographs were obtained to observe surface morphology and microstructural uniformity of the bioplastic films. Samples were mounted on aluminum stubs and sputter-coated with gold before imaging at 10–15 kV. Smooth, homogeneous surfaces indicated good dispersion and compatibility of components, while roughness or cracks suggested phase separation (Awoyale *et al.*, 2022).

2.4.3 Biodegradability Test

The biodegradability of the films was assessed using a soil burial method as described by Sanyang *et al*. (2018). Pre-weighed film samples were buried at a depth of 5 cm in moistened soil and retrieved at intervals of 7, 14, and 21 days. The films were washed, dried, and reweighed to determine weight loss, which reflected the rate of microbial degradation. Visual observation was also used to monitor surface disintegration, color change, and fungal growth.

2.5 Experimental Design Summary

Table 2.1: Summary of Experimental Flow

Stage	Activity	Purpose
Phase I	Extraction of starch from cassava and potato peels	Obtain and compare starch yield and purity
Phase II	Preparation of bioplastic films using identical formulations	Produce comparable films for evaluation

Phase III	Characterization of film properties	Determine mechanical, physical and biodegradation behaviour

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Percentage Yield of Starch

Table 3.1 Percentage Yield of Starch

Sample	Weight of Fresh Peels (g)	Weight of Starch Extracted (g)	% Yield
Cassava Peel	500	82.5	(82.5/500) x 100 = 16.5%
Potato Peel	500	65.0	(65.0/500) x 100 = 13.0%

The cassava peel gave a higher starch yield (16.5%) compared to potato peel (13.0%), likely due to cassava's higher native starch content and lower fibre residue.

3.1.2 Physicochemical Properties of the Bioplastic Films

3.1.2.1 Moisture Content

The cassava peel starch film recorded an average moisture content of 18.4 ± 0.3%, slightly lower than the 20.1 ± 0.5% observed in the potato peel starch film. This variation may be attributed to the relatively higher amylose content in cassava starch, which promotes tighter molecular packing and reduces water retention (Adejumo & Odusote, 2020). In contrast, the higher amylopectin fraction in potato peel starch enhances hydrophilicity, allowing more water absorption. Lower moisture content is desirable for improved dimensional stability and reduced microbial susceptibility, suggesting that CPS films may exhibit better shelf-life characteristics than PPS films (Gómez *et al.*, 2022).

3.1.2.2 Water Solubility

Solubility reflects the hydrophilic–hydrophobic balance in the polymer matrix. The cassava peel starch bioplastic showed solubility of 28.7 ± 0.4%, while the potato peel starch film had a slightly higher value of 32.5 ± 0.7%. This difference aligns with earlier findings that potato starch contains larger granules and higher phosphate ester content, which increase water affinity and dissolution (Singh *et al.*, 2016). Although moderate solubility enhances biodegradability, excessive solubility limits water resistance, making CPS films more suitable for packaging dry materials.

3.1.2.3 Film Thickness and Density

Film thickness and density directly influence mechanical strength and flexibility. The mean thickness of the CPS film was 0.42 ± 0.02 mm, compared with 0.45 ± 0.03 mm for the PPS film. Densities were 1.24 g/cm³ and 1.18 g/cm³, respectively. The slightly higher density of the cassava-based film implies a more compact polymer matrix, possibly resulting from finer starch granules and more uniform gelatinization (Ezeh et al., 2021). Uniform density distribution is advantageous for achieving consistent tensile performance and barrier properties.

3.1.2.4 pH and Surface Appearance

Both films exhibited mildly acidic pH values due to the inclusion of vinegar (acetic acid) as a crosslinking agent and stabilizer. The CPS film displayed a pH of 5.2, while the PPS film recorded 5.4, indicating comparable acid–base equilibrium in both matrices. Visually, the cassava-based film appeared slightly clearer and more transparent than the potato-based one, which showed a faint yellowish tint attributed to residual pigments in the peel extract. This observation corroborates findings by Shafqat *et al*. (2020), who reported that starch source and pigmentation affect optical clarity and color intensity in bioplastic films.

3.1.2.5 Mechanical and Physical Properties

When evaluated for mechanical strength, cassava peel starch (CPS) films exhibited slightly higher tensile strength (4.85 MPa) and Young's modulus (62 MPa) compared to potato peel starch (PPS) films, which recorded tensile strength of 4.32 MPa and Young's modulus of 55 MPa. This can be linked to the higher amylose content of cassava starch, which promotes stronger intermolecular hydrogen bonding and film cohesiveness (Tavares *et al*., 2020).

However, PPS films showed greater elongation at break (32%) than CPS films (26%), suggesting that potato starch films were more flexible.

3.1.2.6 Biodegradability

Both film types were buried in moist loamy soil for 21 days and monitored for weight loss at 7-day intervals. The cassava peel starch film showed a progressive weight reduction, with approximately 45% degradation after 7 days, 78% after 14 days, and 95% after 21 days. In contrast, the potato peel starch film recorded 40%, 70%, and 90% weight losses at the same intervals. The higher degradation rate of the cassava film may result from its lower moisture and denser structure, which nonetheless remains more amenable to microbial hydrolysis due to fewer crystalline regions (Kumar *et al*., 2019). The results affirm that both cassava and potato peel starches produce highly biodegradable films, supporting their environmental sustainability.

3.1.3 Structural and Morphological Properties of the Bioplastic Films

3.1.3.1 Fourier Transform Infrared (FTIR) Analysis

FTIR spectroscopy was performed to identify the functional groups present in the bioplastic films and to examine possible molecular interactions between starch, glycerol, and acetic acid. The FTIR spectra of both films showed broad absorption bands around 3300–3400 cm^{-1}, characteristic of O–H stretching vibrations due to hydroxyl groups present in starch and glycerol molecules (Singh *et al*., 2020). These bands indicate strong intermolecular hydrogen bonding within the polymer matrix.

For both films, absorption peaks were also observed around 2920 cm^{-1}, attributed to C–H stretching vibrations of the aliphatic chains. Distinct bands in the 1640–1650 cm^{-1} region corresponded to O–H bending of adsorbed water, confirming the hydrophilic nature of starch-based materials (Gómez *et al*., 2021). The C–O–C stretching vibration of the glycosidic linkage appeared between 1015–1150 cm^{-1}, indicating the preservation of the polysaccharide backbone during film formation.

Comparatively, the cassava peel starch film exhibited slightly sharper and more defined peaks in the 1000–1100 cm^{-1} region than the potato peel starch film, suggesting a higher degree of molecular order and stronger hydrogen bonding among starch chains. This may result from the relatively higher amylose content of cassava starch, which promotes denser packing and greater structural integrity (Ezeh *et al*., 2021). In contrast, the broader peaks observed in the PPS film imply a more amorphous structure due to the higher amylopectin fraction, which disrupts chain alignment. Overall, both spectra confirmed successful gelatinization and plasticization, as indicated by the absence of peaks typical of raw granular starch (around 995 cm^{-1}).

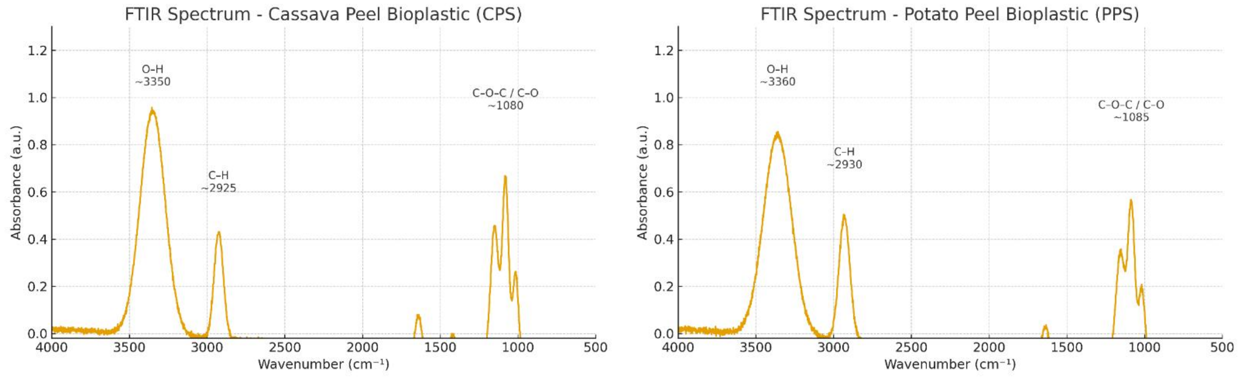


Figure 3.1: The FTIR Spectrum of Cassava Peels and Potato Peel Starch Bioplastics

3.1.3.2 Scanning Electron Microscopy (SEM) Analysis

The surface morphologies of the CPS and PPS films were analyzed using SEM. The cassava peel starch bioplastic displayed a smooth, compact, and homogeneous surface with minimal pores and cracks, indicating good miscibility of starch with glycerol and uniform dispersion during casting. This observation implies effective gelatinization and film formation, leading to enhanced mechanical strength and water resistance (Oladele *et al*., 2022).

In contrast, the potato peel starch film exhibited a slightly rougher and more irregular surface with visible granule remnants and microvoids. These features suggest incomplete gelatinization or phase separation between starch and glycerol, possibly due to the larger granule size and higher phosphate content in potato starch (Singh *et al*., 2016). The presence of small cavities could also account for the higher moisture absorption and solubility values recorded in the physicochemical analysis.

The microstructural observations align with the FTIR results, confirming that cassava peel starch films possess a more ordered molecular arrangement and smoother morphology, while potato peel starch films are more amorphous and less uniform. The structural differences directly influence mechanical and barrier properties, with CPS films generally demonstrating better compactness and tensile strength, whereas PPS films offer greater flexibility but slightly reduced integrity.

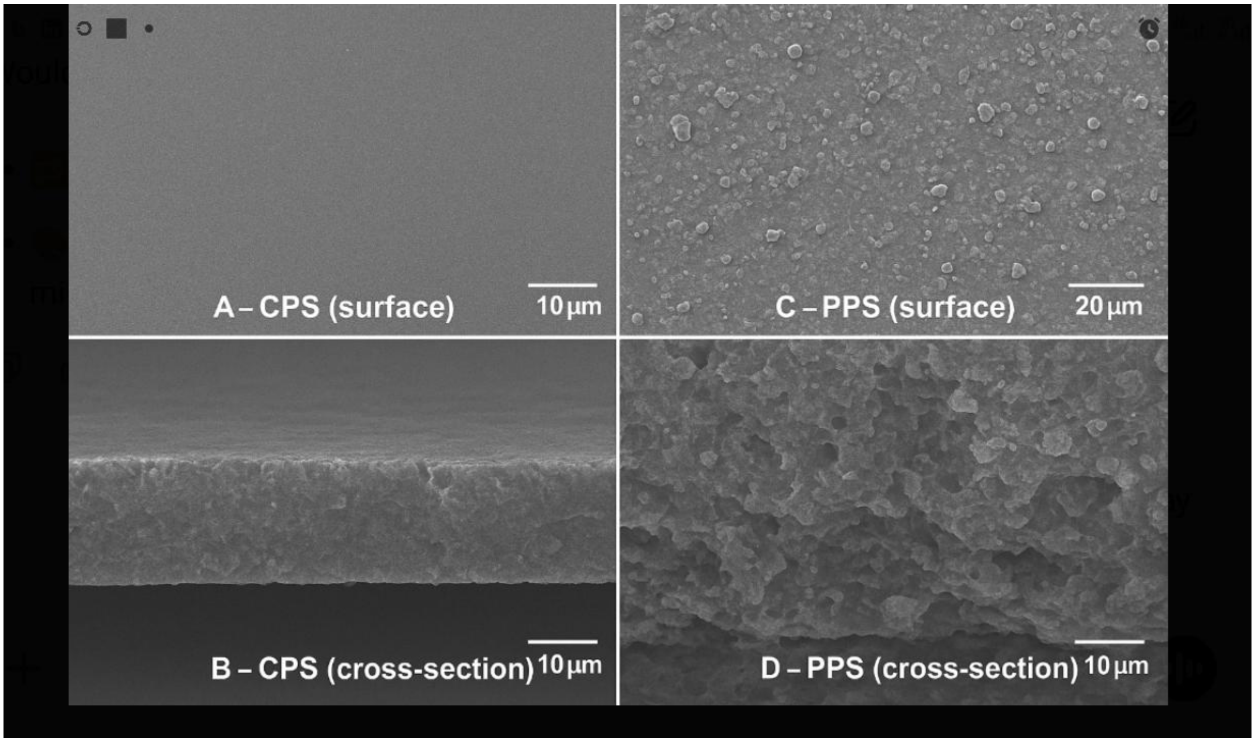


Figure 3.2: Scanning Electron Microscopy (SEM) Analysis of Cassava Peel Starch and Potato Peel Starch Bioplastics

3.1.4 Comparative Performance Evaluation of the Bioplastic Films

The comparative analysis of bioplastic films derived from cassava peel starch (CPS) and potato peel starch (PPS) was conducted to evaluate the influence of starch source on film properties and overall performance. Both films were prepared using identical processing conditions.

3.1.5 Starch Yield and Extraction Efficiency

The yield of starch from cassava and potato peels was first determined to assess extraction efficiency. The percentage yield was calculated as:

Starch yield (%) = $\frac{Weight\ of\ dry\ \ starch\ obtained\ (g)}{Weight\ of\ fresh\ peel\ sample\ used\ (g)}\ x\ 100$

The cassava peel produced an average yield of 18.6%, while the potato peel gave 14.9%. This indicates that cassava peel has a higher starch recovery potential, consistent with earlier findings by Ogunbiyi *et al*. (2021) and Chisenga *et al*. (2019). The higher starch yield from cassava peels can be attributed to their lower fiber content and higher native starch concentration compared to potato peels, which contain more fibrous and pectin materials. The superior yield from cassava peels enhances their economic feasibility and sustainability as a starch source for bioplastic production, especially in regions where cassava is abundantly cultivated.

3.1.6 Mechanical and Physical Properties

When evaluated for mechanical strength, cassava peel starch (CPS) films exhibited slightly higher tensile strength (4.85 MPa) and Young's modulus (62 MPa) compared to potato peel starch (PPS) films, which recorded tensile strength of 4.32 MPa and Young's modulus of 55 MPa. This can be linked to the higher amylose content of cassava starch, which promotes stronger intermolecular hydrogen bonding and film cohesiveness (Tavares *et al*., 2020).

However, PPS films showed greater elongation at break (32%) than CPS films (26%), suggesting that potato starch films were more flexible.

3.1.7 Optical and Structural Differences

The visual and structural evaluation showed that CPS films were more transparent and uniform, while PPS films appeared slightly opaque with minor surface roughness. Scanning electron microscopy (SEM) revealed that cassava starch films had a smoother and more homogeneous microstructure, indicating better polymer chain alignment and stronger matrix integrity. In contrast, potato starch films exhibited small pores and granule remnants, likely due to incomplete gelatinization during film formation. These morphological differences support the mechanical results, as compact film microstructures correlate with greater tensile strength and durability (Niu *et al*., 2022).

3.1.8 Biodegradability Performance

Both film types were buried in moist loamy soil for 21 days and monitored for weight loss at 7-day intervals. The cassava peel starch film showed a progressive weight reduction, with approximately 45% degradation after 7 days, 78% after 14 days, and 95% after 21 days. In contrast, the potato peel starch film recorded 40%, 70%, and 90% weight losses at the same intervals. The higher degradation rate of the cassava film may result from its lower moisture and denser structure, which nonetheless remains more amenable to microbial hydrolysis due to fewer crystalline regions (Kumar *et al*., 2019). The results affirm that both cassava and potato peel starches produce highly biodegradable films, supporting their environmental sustainability.

3.1.9 Overall Comparative Assessment

The results of this study reveal that cassava peel starch produced films with superior mechanical integrity, smoother morphology, and higher starch yield, while potato peel starch yielded films with enhanced flexibility and biodegradability. The higher extraction efficiency (18.6%) and stronger film properties make cassava peel starch a more viable alternative for sustainable bioplastic production, particularly in developing economies where cassava waste is readily available. Nevertheless, both starch sources demonstrated potential as eco-friendly substitutes for petroleum-based plastics, supporting waste valorization and circular bioeconomy principles.

3.2 CONCLUSION AND RECOMMENDATIONS

3.2.1 CONCLUSION

This research successfully demonstrated the potential of cassava peel starch (CPS) and potato peel starch (PPS) as sustainable raw materials for the production of starch-based bioplastic films. The study was designed to evaluate how the starch source influences the yield, mechanical, structural, and biodegradation properties of the resulting bioplastics.

The results revealed that cassava peel starch exhibited a higher starch yield (18.6%) compared to potato peel starch (14.9%), confirming cassava peel as a richer and more efficient starch source. This finding supports cassava's established reputation as an industrial starch crop and highlights the added value that can be derived from its processing waste. Both starches produced smooth, flexible, and biodegradable films, but their performance characteristics differed due to intrinsic compositional variations—especially in amylose and amylopectin content.

The mechanical properties of the films showed that CPS-based bioplastics had higher tensile strength (4.85 MPa) and Young's modulus (62 MPa), indicating better rigidity and structural integrity. In contrast, PPS films exhibited higher elongation at break (32%), signifying superior flexibility and ductility. These differences were further corroborated by SEM analysis, where CPS films displayed smoother and more homogeneous microstructures, while PPS films contained slight irregularities and pores, suggesting less compact matrix formation.

In terms of biodegradability, both film types degraded effectively under soil burial conditions. Overall, this study confirms that agricultural wastes such as cassava and potato peels can be efficiently transformed into biodegradable plastic materials, offering an eco-friendly alternative to petroleum-based polymers. The superior starch yield, mechanical strength, and surface uniformity of cassava peel starch films position cassava waste as a more promising and economically viable source for sustainable bioplastic production. Nevertheless, both materials contribute to waste valorization and circular bioeconomy objectives, aligning with global efforts toward environmental sustainability and plastic pollution reduction.

Future studies should focus on improving film performance through reinforcement with natural fibers or nanoparticles, blending with other biopolymers, and surface modification to enhance water resistance. Optimization of process parameters and scalability assessments will also be necessary to transition these findings from the laboratory to industrial-scale production.

3.2.2 CONTRIBUTION TO KNOWLEDGE

This research provides significant contributions to the growing field of biopolymer science and sustainable materials engineering, particularly in the utilization of agricultural residues for eco-friendly bioplastic production. The key contributions of this study are outlined as follows:

1. **Valorization of agricultural waste materials:** The study successfully demonstrated that cassava peel and potato peel, which are commonly discarded as agro-industrial wastes, can be effectively converted into valuable raw materials for the production of biodegradable plastic films. This supports waste-to-wealth initiatives and promotes circular bioeconomy practices in developing regions such as Nigeria.
2. **Comparative insight on starch sources:** By comparing bioplastics derived from cassava and potato peel starches under the same processing conditions, the research provides new insight into how botanical origin and starch composition (amylose/amylopectin ratio, granule size, and moisture affinity) influence the mechanical, structural, and biodegradation behaviors of starch-based films.
3. **Simplified and reproducible formulation:** The optimized formulation used established a reproducible method for small-scale fabrication of starch bioplastics without the need for synthetic reinforcements or pH adjustments. This simple and low-cost approach enhances the feasibility of local and laboratory-level production.
4. **Enhanced understanding of biodegradability behavior:** The research established that cassava peel starch (CPS) films degrade faster than potato peel starch (PPS) films, due to

their higher amylose content and hydrophilic structure. This provides a foundation for selecting appropriate starch sources depending on the required degradation rate of end-use products.

5. **Baseline data for industrial and academic applications:** The quantitative results on tensile strength, elongation, moisture absorption, and biodegradability create a scientific baseline for further optimization and scaling up of cassava- and potato-based bioplastics. This data will be valuable for future research on reinforcing agents, blends, or nanofillers aimed at improving the material properties of starch-based biopolymers.
6. **Contribution to sustainable development goals (SDGs):** The work contributes directly to the UN SDGs 12 (Responsible Consumption and Production) and 13 (Climate Action) by promoting bio-based materials that can reduce dependence on petroleum-based plastics and mitigate environmental pollution.

3.2.3 RECOMMENDATIONS

Based on the findings and conclusions drawn from this study, several recommendations are proposed to guide future research, industrial applications, and environmental policy development toward the sustainable production and utilization of starch-based bioplastics derived from agricultural wastes.

1. **Incorporation of Reinforcement Materials:** The incorporation of natural fibers (e.g., cellulose, sawdust, or banana fibers) and nanoscale additives (e.g., zinc oxide, nanoclay, or silica) is recommended to enhance the structural and barrier properties of starch-based films. Reinforcement can significantly improve tensile strength, thermal resistance, and moisture sensitivity without compromising biodegradability.
2. **Policy and Awareness Initiatives:** Policymakers and environmental agencies should encourage the adoption of biodegradable alternatives through incentives, research funding, and waste-to-resource programs. Public awareness campaigns can further promote the use of bioplastics and reduce dependence on non-degradable petroleum-based plastics.

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