

# Development of Biodegradable Food Packaging Films from Cassava Starch

Abu Sunday Ojima

Department of Food Technology, Federal Polytechnic Idah, Nigeria

Eze Harrison Felix

Department of Industrial Chemistry, Enugu State University of Science and Technology, Nigeria

Adedoyin Bukola Emily

Department of Food Science and Technology, The Federal University of Technology, Akure, Nigeria

Blessing Oboh Ejiyere

School: Ambrose Alli University, Ekpoma Edo State Nigeria  
Department: Computer Science

## Abstract

The increasing environmental impact of petroleum-based plastic packaging has encouraged the development of biodegradable food packaging materials from renewable resources. Cassava starch is a promising biopolymer because it is abundant, inexpensive, edible, renewable, biodegradable, and capable of forming continuous films. However, native cassava starch films are often brittle and highly sensitive to moisture, limiting their food packaging applications. This study developed biodegradable food packaging films from cassava starch using glycerol as a plasticizer and plant fiber powder as a reinforcing additive. Five formulations were prepared by the solution casting method and evaluated for physical, mechanical, barrier, optical, biodegradation, and food packaging properties. The results showed that increasing glycerol concentration improved flexibility but reduced tensile strength and water resistance. The addition of plant fiber powder improved tensile strength, reduced water solubility, water absorption, and water vapor permeability, and increased opacity. Soil burial analysis confirmed progressive biodegradation over 28 days. Bread packaging tests showed that cassava starch films reduced moisture loss and delayed visible mold growth compared with unpackaged bread. The formulation containing 2% plant fiber powder showed the best overall performance,

indicating its potential as biodegradable packaging for dry and short-shelf-life foods.

**Keywords:** Cassava starch; biodegradable film; food packaging; glycerol; plant fiber powder; water vapor permeability; soil biodegradation; sustainable packaging.

## 1. Introduction

Food packaging is an essential component of the food supply chain because it protects food products from physical damage, microbial contamination, oxygen, light, moisture transfer, and quality deterioration. Conventional petroleum-based plastics such as polyethylene, polypropylene, polystyrene, and polyvinyl chloride are widely used because they are lightweight, inexpensive, flexible, durable, and have good barrier properties. However, these plastics are persistent in the environment and contribute significantly to global plastic pollution. Jambeck et al. reported that large quantities of plastic waste enter aquatic environments annually, while later reviews have emphasized that food packaging is one of the major contributors to plastic waste generation (Jambeck et al., 2015; Ncube et al., 2020). The environmental challenges caused by plastic packaging have increased research interest in biodegradable materials from renewable resources (Siracusa et al., 2008; Tharanathan, 2003; Rhim et al.,

2013). Biodegradable food packaging materials are designed to decompose through biological activity under suitable environmental conditions. Such materials may reduce the accumulation of plastic waste and dependence on fossil-based polymers. Biodegradable films can be prepared from polysaccharides, proteins, lipids, polyesters, microbial polymers, and their composites (Falguera et al., 2011; Han, 2014; Otoni et al., 2017). Recent studies also show growing interest in active, intelligent, and multifunctional biodegradable packaging systems for improving food quality and safety while reducing plastic pollution. A recent review on biodegradable and smart packaging films highlighted renewable polymers, including polysaccharides and proteins, as important materials for future sustainable packaging systems. Among natural polymers, starch is one of the most promising materials for biodegradable packaging because it is abundant, inexpensive, edible, renewable, biodegradable, and capable of forming films after gelatinization (Krochta & De Mulder-Johnston, 1997; Mali et al., 2005; Jiménez et al., 2012). Reviews on starch-based packaging report that starch films are attractive alternatives to petrochemical plastics because of their low cost, availability, biodegradability, and film-forming ability. However, starch-based films generally suffer from poor moisture resistance, mechanical fragility, and limited barrier performance, which restrict their direct use in food packaging applications. Cassava starch is particularly suitable for biodegradable film development because cassava is widely cultivated in tropical and subtropical regions, especially in Africa, Asia, and Latin America. Cassava starch is cheap, renewable, biodegradable, and easily extracted from cassava roots. It also has good film-forming ability when dispersed in water and gelatinized by heat. Previous studies have reported that cassava starch can be used to prepare edible and biodegradable films for food packaging applications (Müller et al., 2008; Souza et al., 2012; Pelissari et al., 2013). A recent review on cassava starch films reported increasing research interest over the last decade, especially in studies involving glycerol plasticization, starch modification, nanofillers, natural extracts, and biodegradable composites. Despite its potential, native cassava starch films have important

limitations. They are commonly brittle, hydrophilic, and mechanically weaker than synthetic plastic films. These limitations are mainly caused by the strong hydrogen bonding among starch chains and the presence of hydroxyl groups that interact with water (García et al., 2000; Bertuzzi et al., 2007; Vieira et al., 2011). As a result, cassava starch films may show high water absorption, high water solubility, and high-water vapor permeability under humid conditions. Research on cassava starch-based films has shown that glycerol content significantly affects tensile and barrier properties; lower glycerol levels generally provide better tensile and barrier performance, while higher glycerol levels increase flexibility.

Glycerol is commonly used as a plasticizer in starch-based films because it reduces intermolecular interactions between starch chains and improves flexibility. However, excessive glycerol can reduce tensile strength, increase water sensitivity, and increase water vapor permeability (Müller et al., 2008; Zhang & Han, 2006; Vieira et al., 2011). Recent cassava starch film studies using glycerol and other natural plasticizers, such as honey, confirm that plasticizer type and concentration influence moisture content, water vapor permeability, and film performance. Therefore, glycerol concentration must be optimized to balance film flexibility, strength, and water resistance. Plant fiber powder can be incorporated into cassava starch films as a natural reinforcing additive. Natural fibers contain cellulose, hemicellulose, and lignin, which may improve tensile strength, reduce water absorption, and create a more compact polymer matrix. Agricultural residues such as cassava peel, banana peel, onion peel, coconut fiber, and sugarcane bagasse are especially attractive because they are low-cost, renewable, and support waste valorization. Recent research on cassava bagasse-filled cassava starch films showed that cassava by-products can be used as fillers in glycerol-plasticized cassava starch films produced by casting. This supports the use of agricultural fiber residues as reinforcing agents in starch-based biodegradable packaging films. Therefore, this study focuses on the development and characterization of biodegradable food packaging films from cassava starch using glycerol as a plasticizer and plant fiber powder as a reinforcing

additive. The films are evaluated for physical, mechanical, barrier, optical, biodegradation, and food packaging properties. The study is intended to identify a suitable formulation with improved strength, flexibility, water resistance, biodegradability, and food packaging performance.

## 2. Literature Review

### 2.1 Biodegradable Food Packaging

Biodegradable food packaging has become an important research area because of the environmental impacts of petroleum-based plastics. Traditional plastics provide excellent strength, flexibility, and barrier properties, but they are slow to degrade and contribute to long-term pollution (Marsh & Bugusu, 2007; Siracusa et al., 2008; Jambeck et al., 2015). Biodegradable packaging materials are produced from renewable or compostable polymers that can break down through microbial activity under suitable conditions. These materials can reduce plastic accumulation and support more sustainable food packaging systems (Tharanathan, 2003; Rhim et al., 2013; Dilkes-Hoffman et al., 2019). Biodegradable food packaging materials include polysaccharides, proteins, lipids, polyesters, and microbial polymers. Polysaccharides such as starch, cellulose, chitosan, pectin, and alginate are widely studied because they are abundant, renewable, and generally safe for food-contact applications (Krochta & De Mulder-Johnston, 1997; Falguera et al., 2011; Han, 2014). Recent reviews show that biodegradable packaging research is moving beyond simple passive films toward active and intelligent systems that can improve food safety, monitor freshness, and extend shelf life. However, biodegradable films still face major challenges, including high water sensitivity, low mechanical strength, poor gas barrier performance, high production cost, and limited industrial scalability (Rhim et al., 2013; Ncube et al., 2020).

### 2.2 Starch as a Film-Forming Material

Starch is one of the most widely investigated biopolymers for biodegradable packaging. It is composed mainly of amylose and amylopectin. Amylose contributes strongly to film formation because of its mostly linear molecular structure, while amylopectin influences flexibility, crystallinity, and

structural arrangement (Mali et al., 2005; Jiménez et al., 2012; Cano et al., 2015). During gelatinization, starch granules absorb water, swell, and release amylose, resulting in a viscous film-forming solution. During drying, starch chains reorganize and form a continuous film matrix through hydrogen bonding (García et al., 2000; Bertuzzi et al., 2007). Starch films are attractive because they are renewable, biodegradable, edible, non-toxic, and inexpensive. Current reviews identify starch as one of the best candidates for biodegradable packaging because of its abundance, low cost, thermoplastic behavior, and film-forming ability. However, starch films have poor moisture resistance because of the hydrophilic nature of starch molecules. They also often have weak mechanical properties compared with petroleum-based plastics. Recent reviews continue to identify moisture sensitivity, mechanical weakness, and scalability as major challenges in starch-based film development.

### 2.3 Cassava Starch for Biodegradable Films

Cassava starch is a valuable raw material for biodegradable packaging films because cassava is widely available in many tropical regions. Cassava starch is relatively inexpensive, renewable, edible, biodegradable, and suitable for film formation using simple techniques such as solution casting (Müller et al., 2008; Souza et al., 2012; Pelissari et al., 2013). Cassava starch films are particularly relevant in cassava-producing countries because they can support local value addition and reduce dependence on imported petroleum-based packaging materials. Several studies have investigated cassava starch films for food packaging applications. Müller et al. (2008) studied the influence of glycerol and sorbitol on water barrier properties of cassava starch films. Souza et al. (2012) investigated cassava starch biodegradable films containing glycerol and clay nanoparticles and reported that glycerol content significantly influenced tensile and barrier properties. A recent review focusing on cassava starch films reported that the field has grown over the past decade, with increasing attention to plasticizers, active compounds, and reinforcing agents. Cassava starch films can be produced using the solution casting method. This method involves dispersing starch in water, heating the suspension until gelatinization, adding

plasticizer and fillers, pouring the solution onto flat plates, drying, and peeling the film (García et al., 2000; Mali et al., 2005; Bertuzzi et al., 2007). Although solution casting is useful for laboratory-scale development, industrial production may require scalable methods such as extrusion, coating, compression molding, or continuous casting. Recent reviews highlight casting, extrusion, and coating as important fabrication techniques for biodegradable food packaging films.

#### **2.4 Role of Glycerol as a Plasticizer**

Plasticizers are essential in starch-based films because native starch films are often brittle. Glycerol is one of the most commonly used plasticizers because it is compatible with starch, relatively inexpensive, non-volatile, and effective in increasing film flexibility (Vieira et al., 2011; Zhang & Han, 2006). Glycerol reduces hydrogen bonding between starch chains and increases chain mobility, producing softer and more stretchable films. However, glycerol also has disadvantages. Increasing glycerol concentration may reduce tensile strength, Young's modulus, and water vapor barrier performance because it increases free volume and hydrophilicity in the starch matrix (Müller et al., 2008; Souza et al., 2012; Basiak et al., 2018). Souza et al. found that lower glycerol content in cassava starch films produced better tensile and barrier properties than higher glycerol content. A recent study using glycerol/honey plasticizers in cassava starch films also showed that plasticizer composition influenced moisture content and water vapor permeability. Therefore, glycerol must be used at an optimized concentration to avoid excessive weakening and water sensitivity.

#### **2.5 Plant Fiber Reinforcement and Agricultural Waste Valorization**

Plant fibers are increasingly used to reinforce biodegradable films because they can improve mechanical strength, dimensional stability, and water resistance. Natural fibers are mainly composed of cellulose, hemicellulose, and lignin, and these components can interact with starch to form a stronger and more compact matrix (Otoni et al., 2017; Rhim et al., 2013). Reinforcing additives can also create a tortuous pathway that reduces the movement of water vapor through the film, improving

barrier performance. Agricultural residues are especially useful as fillers because they are renewable, low-cost, and often underutilized. Cassava peel, cassava bagasse, banana peel, onion peel, coconut fiber, and sugarcane bagasse may serve as reinforcing materials in biodegradable films. The use of these residues supports circular economy principles by converting agricultural waste into value-added packaging materials. Recent research on cassava bagasse-filled cassava starch films demonstrated the use of cassava agro-industrial waste as filler in glycerol-plasticized cassava starch films produced by casting. Similarly, cassava root cortex extract has been incorporated into cassava starch films for sustainable packaging applications, showing growing interest in cassava by-products as functional film components.

#### **2.6 Barrier, Optical, and Mechanical Properties of Starch-Based Films**

The performance of food packaging films depends strongly on their mechanical, barrier, and optical properties. Mechanical properties such as tensile strength, elongation at break, and Young's modulus determine whether a film can withstand handling, wrapping, transportation, and storage (Mali et al., 2005; Bertuzzi et al., 2007). Barrier properties such as water vapor permeability and oxygen permeability determine whether the film can control moisture and gas transfer between the food and the environment (Krochta & De Mulder-Johnston, 1997; Siracusa et al., 2008). Starch-based films generally have good oxygen barrier properties under dry conditions but weak water vapor barrier properties under humid conditions because starch is hydrophilic (Jiménez et al., 2012; Cano et al., 2015). A review on polysaccharide-based films noted that high water vapor permeability is a key limitation restricting their application in food packaging. Optical properties are also important because transparent films improve product visibility, while opaque or UV-blocking films may protect light-sensitive foods (Faluera et al., 2011; Otoni et al., 2017). Reinforcing fillers and plant powders usually increase opacity and reduce transparency, which can be beneficial or undesirable depending on the packaged product.

#### **2.7 Active Food Packaging Potential**

Biodegradable films can also function as active packaging when antimicrobial or antioxidant agents are incorporated. Active packaging materials interact with the food or headspace to delay microbial growth, oxidation, moisture migration, or quality loss (Appendini & Hotchkiss, 2002; Han, 2014). Natural additives such as essential oils, plant extracts, phenolic compounds, organic acids, and agricultural by-products have been widely studied as active components in biodegradable films (Otoni et al., 2017; Falguera et al., 2011). Cassava starch films can serve as carriers for active compounds. Recent studies have investigated cassava starch films containing honey, plant extracts, clove oil, and cassava by-products for improved functional properties. This suggests that cassava starch films can be developed not only as passive biodegradable packaging but also as active packaging systems for extending food shelf life.

### 2.8 Biodegradation of Cassava Starch Films

Cassava starch films are biodegradable because starch can be hydrolyzed and metabolized by microorganisms in soil, compost, and other natural environments. During biodegradation, microorganisms produce enzymes that break starch into smaller molecules, which are further converted into carbon dioxide, water, methane, biomass, and other natural products (Tharanathan, 2003; Dilkes-Hoffman et al., 2019). Soil burial tests are commonly used to evaluate biodegradation by measuring film weight loss over time. The biodegradation rate of cassava starch films depends on formulation, film thickness, moisture content, soil conditions, microbial population, temperature, and additive type. Films with higher glycerol content may degrade faster because they absorb more moisture and become more accessible to microorganisms. Reinforced films may degrade more slowly because fillers can increase matrix compactness, but they may still remain biodegradable if the components are natural and microbially degradable. Current reviews note that although starch-based films are biodegradable, their real environmental behavior depends on formulation and disposal conditions.

### 2.9 Food Packaging Application and Research Gap

Cassava starch films have potential for packaging dry foods, bakery products, snacks, fruits, vegetables, and short-shelf-life foods. However, their high-water sensitivity makes them less suitable for high-moisture foods unless improved by reinforcement, blending, coating, or active additives. Research on PLA/cassava starch-based films has shown that cassava starch can be used in biodegradable packaging systems for food applications, including modified-atmosphere packaging. Nevertheless, commercial replacement of petroleum-based plastics remains difficult because starch films must meet practical requirements for strength, flexibility, barrier performance, safety, scalability, cost, and consumer acceptance. Although cassava starch films have been widely studied, there remains a need to optimize the balance between flexibility, strength, water resistance, biodegradability, and food packaging performance. Glycerol improves flexibility but may reduce strength and water resistance, while plant fiber powder may improve strength and barrier properties but reduce transparency and flexibility. Therefore, this study addresses this gap by combining glycerol plasticization with plant fiber reinforcement in cassava starch films and evaluating the resulting films for physical, mechanical, barrier, optical, biodegradation, and food packaging properties.

## 3. Materials and Methods

### 3.1 Materials

Cassava starch was used as the main film-forming biopolymer for the preparation of biodegradable food packaging films. Food-grade glycerol was used as a plasticizer to improve the flexibility of the starch-based films. Distilled water was used as the solvent for starch dispersion and gelatinization. Plant fiber powder was used as a natural reinforcing additive to improve the strength and water resistance of the films. The plant fiber powder may be obtained from agricultural residues such as cassava peel, banana peel, coconut fiber, onion peel, sugarcane bagasse, or another locally available plant-based waste material. Before use, the plant material should be washed, dried, ground, and sieved to obtain fine powder. The equipment required for the study included a digital weighing balance, beakers, measuring cylinders, magnetic stirrer or glass rod, hot plate, drying oven, casting

plates or Petri dishes, digital micrometer, desiccator, universal testing machine, UV-visible spectrophotometer, soil container, and analytical balance.

### 3.2 Experimental Design

Five cassava starch film formulations were prepared to study the effects of glycerol concentration and plant fiber powder addition

on film properties. Formulations F1, F2, and F3 contained cassava starch and different glycerol concentrations without plant fiber powder. Formulations F4 and F5 contained cassava starch, glycerol, and plant fiber powder.

Table 1. Experimental formulation of cassava starch biodegradable films

Sample code	Cassava starch (g)	Glycerol (g)	Distilled water (mL)	Additive type	Additive concentration (%)
F1	4.00	1.00	100	None	0
F2	4.00	1.50	100	None	0
F3	4.00	2.00	100	None	0
F4	4.00	1.50	100	Plant fiber powder	1
F5	4.00	1.50	100	Plant fiber powder	2

### 3.3 Preparation of Plant Fiber Powder

The selected plant fiber material was washed thoroughly with clean water to remove dirt, dust, and other impurities. The cleaned material was cut into small pieces and dried in an oven at 50–60°C until constant weight was achieved. The dried material was then ground using a laboratory grinder and sieved to obtain fine particles of uniform size. The prepared plant fiber powder was stored in an airtight container at room temperature until use. The purpose of adding plant fiber powder was to reinforce the cassava starch matrix and improve mechanical strength, water resistance, and barrier performance.

### 3.4 Preparation of Cassava Starch Films

Cassava starch was weighed according to the formulations shown in Table 1 and dispersed in 100 mL of distilled water. The mixture was stirred continuously until a uniform starch

suspension was obtained. Glycerol was then added to the suspension as a plasticizer and mixed thoroughly. The starch-glycerol suspension was heated at 80–90°C for 20–30 minutes under continuous stirring to allow starch gelatinization. During gelatinization, the starch granules absorbed water, swelled, and produced a viscous film-forming solution. For F4 and F5, plant fiber powder was added after gelatinization and mixed until evenly dispersed in the film-forming solution. The solution was then poured into clean, flat casting plates and dried in an oven at 45–50°C for 24 hours. After drying, the films were carefully peeled from the casting plates and conditioned at room temperature for 48 hours before characterization.

### Figure 1. Flow chart for preparation of cassava starch biodegradable films

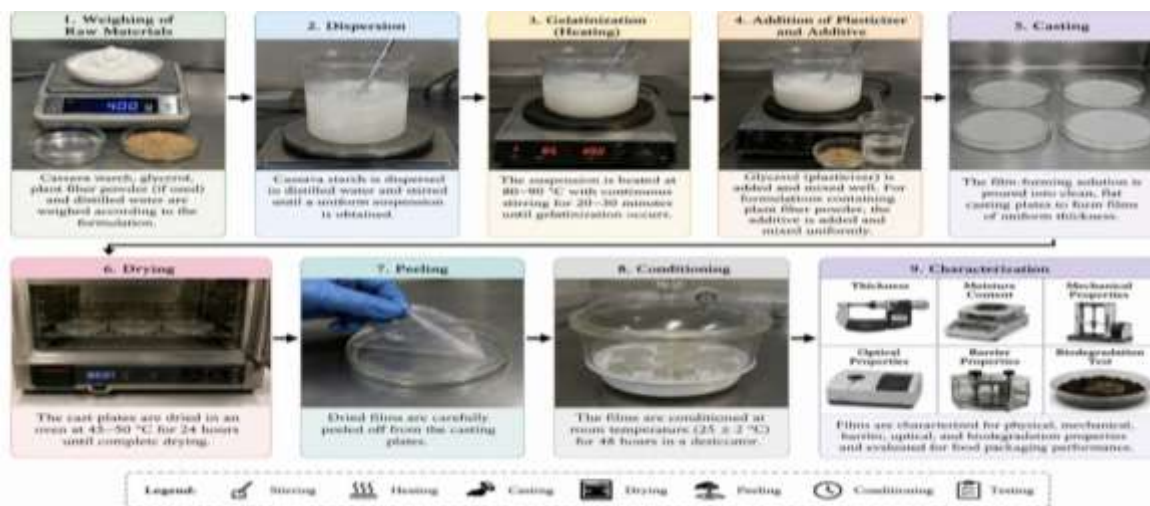


Figure 1 shows the preparation process of cassava starch biodegradable films. The process involved weighing of raw materials, dispersion of cassava starch in distilled water, addition of glycerol, gelatinization by heating, incorporation of plant fiber powder, casting, drying, peeling, conditioning, and characterization.

The physical appearance of the cassava starch films was evaluated by visual observation. The films were examined for color, transparency, opacity, surface smoothness, flexibility, uniformity, cracks, bubbles, and visible particles.

### 3.5 Physical Appearance of Films

**Figure 2. Physical appearance of cassava starch films prepared with different formulations**

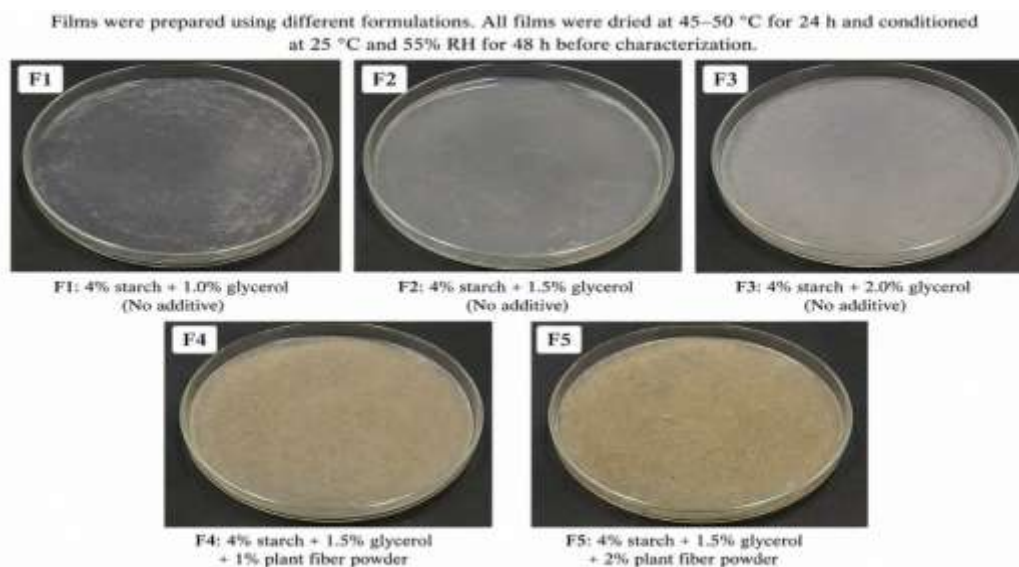


Figure 2 shows the physical appearance of cassava starch films prepared using different formulations. F1–F3 represent films without plant fiber powder at different glycerol concentrations, while F4 and F5 represent films containing 1% and 2% plant fiber powder, respectively.

### 3.6 Film Thickness

Film thickness was measured using a digital micrometer. Measurements were taken at five different positions on each film, including the center and four edges. The mean thickness was calculated and expressed in millimeters.

### 3.7 Moisture Content

Moisture content was determined by drying film samples in an oven at 105°C until constant weight was obtained. The initial weight and final dry weight of each sample were recorded. Moisture content was calculated using Equation 1:

$$\text{Moisture content(\%)} = \frac{W_i - W_f}{W_i} \times 100$$

where  $W_i$  is the initial weight of the film sample and  $W_f$  is the final dry weight of the film sample.

### 3.8 Water Solubility

Water solubility was determined by immersing dried film samples in distilled water for 24 hours at room temperature. After immersion, the remaining undissolved film portions were removed and dried again until constant weight. Water solubility was calculated using Equation 2:

$$\text{Water solubility(\%)} = \frac{W_0 - W_1}{W_0} \times 100$$

where  $W_0$  is the initial dry weight of the film and  $W_1$  is the final dry weight after immersion.

### 3.9 Water Absorption

Water absorption was determined by weighing dry film samples and immersing them in distilled water for a fixed period. After immersion, the samples were removed, and excess surface water was gently wiped using tissue paper. The wet weight was then recorded. Water absorption was calculated using Equation 3:

$$\text{Water absorption(\%)} = \frac{W_w - W_d}{W_d} \times 100$$

where  $W_w$  is the wet weight of the film and  $W_d$  is the dry weight of the film.

### 3.10 Mechanical Properties

Mechanical properties were determined using a universal testing machine. Film samples were cut into rectangular strips of uniform size. The strips were mounted between the

grips of the machine and stretched until breakage.

Tensile strength, elongation at break, and Young's modulus were recorded. Tensile strength was calculated using Equation 4:

$$\text{Tensile strength} = \frac{\text{Maximum force}}{\text{Cross-sectional area}}$$

Elongation at break was calculated using Equation 5:

$$\text{Elongation at break(\%)} = \frac{L_f - L_0}{L_0} \times 100$$

where  $L_0$  is the original length of the film strip and  $L_f$  is the final length of the film strip at break.

### 3.11 Water Vapor Permeability

Water vapor permeability was determined using the gravimetric cup method. Film samples were sealed over the opening of test cups containing distilled water or desiccant. The cups were placed under controlled temperature and relative humidity conditions. The weight change of each cup was recorded at regular intervals. The water vapor transmission rate was calculated from the slope of weight change over time, and water vapor permeability was then determined.

### 3.12 Optical Properties

The optical properties of the films were measured using a UV-visible spectrophotometer. Film samples were cut into suitable sizes and placed in the spectrophotometer sample holder. Light transmittance was measured at 600 nm. Film opacity was calculated based on absorbance and film thickness. A higher opacity value indicated lower transparency and greater ability to block light.

### 3.13 Soil Burial Biodegradation Test

The biodegradability of the cassava starch films was evaluated using a soil burial test. Film samples were cut into equal sizes, dried, and weighed before burial. The samples were buried in moist soil at a depth of approximately 5 cm. Samples were removed after 7, 14, 21, and 28 days. The retrieved films were carefully cleaned, dried, and weighed. Percentage weight loss was calculated using Equation 6:

$$\text{Weight loss(\%)} = \frac{W_0 - W_t}{W_0} \times 100$$

where  $W_0$  is the initial dry weight before burial and  $W_t$  is the dry weight after burial time.

### 3.14 Food Packaging Performance Test

Bread was used as a model food product to assess the packaging performance of the developed films. Bread samples were wrapped with selected cassava starch films and stored at room temperature. An unpackaged bread sample and a bread sample wrapped with commercial plastic film were used as controls. The samples were observed for five days. Moisture loss, visible mold growth, texture, and overall acceptability were recorded. Moisture loss was determined by weighing the bread samples before and after storage.

### 3.15 Statistical Analysis

All analyses were carried out in triplicate. Results were expressed as mean  $\pm$  standard deviation. One-way analysis of variance was used to determine significant differences among film formulations. Differences were considered statistically significant at  $p < 0.05$ . Statistical analysis may be performed using SPSS, Excel, GraphPad Prism, R, or any suitable statistical software.

## 4. Results and Discussion

### 4.1 Physical Appearance of Cassava Starch Films

The cassava starch films were successfully prepared using the solution casting method. All formulations produced continuous films that could be peeled from the casting plates after drying. The films differed in transparency, flexibility, surface appearance, and opacity depending on glycerol concentration and plant fiber powder addition. Films F1, F2, and F3, which did not contain plant fiber powder, appeared smoother and more transparent than F4 and F5. F1 appeared firmer and less flexible because it contained the lowest glycerol concentration. F2 showed improved flexibility and better handling properties. F3 appeared softer and more flexible due to its higher glycerol content. Films F4 and F5 appeared more opaque because of the incorporation of plant fiber powder. F5 showed the highest opacity and a slightly rougher surface, which may be due to the higher fiber concentration.

### 4.2 Physical Properties of Cassava Starch Films

The physical properties of the cassava starch films are presented in Table 2. Film thickness ranged from  $0.112 \pm 0.004$  mm to  $0.128 \pm 0.006$  mm. Thickness increased slightly with increasing glycerol and plant fiber powder concentration. This may be attributed to the increase in total solid content in the film-forming solution.

**Table 2. Physical properties of cassava starch films**

Sample code	Thickness (mm)	Moisture content (%)	Water solubility (%)	Water absorption (%)
F1	$0.112 \pm 0.004$	$13.85 \pm 0.42$	$34.20 \pm 1.10$	$78.45 \pm 2.35$
F2	$0.118 \pm 0.003$	$15.20 \pm 0.38$	$37.65 \pm 1.25$	$84.30 \pm 2.10$
F3	$0.126 \pm 0.005$	$17.80 \pm 0.51$	$42.15 \pm 1.40$	$91.75 \pm 2.90$
F4	$0.121 \pm 0.004$	$14.60 \pm 0.33$	$31.85 \pm 1.05$	$72.50 \pm 2.20$
F5	$0.128 \pm 0.006$	$13.95 \pm 0.45$	$29.40 \pm 0.95$	$68.25 \pm 1.85$

Moisture content increased as glycerol concentration increased. F1 recorded  $13.85 \pm 0.42\%$ , while F3 recorded the highest value of  $17.80 \pm 0.51\%$ . This increase may be due to the hydrophilic nature of glycerol, which attracts and retains water molecules in the

starch matrix. The high number of hydroxyl groups in both starch and glycerol promotes water binding, resulting in increased moisture content. Water solubility also increased with glycerol concentration. F1 showed a water solubility of  $34.20 \pm 1.10\%$ , while F3 showed

42.15 ± 1.40%. Similarly, water absorption increased from 78.45 ± 2.35% in F1 to 91.75 ± 2.90% in F3. These results suggest that increasing glycerol concentration reduced the water resistance of the cassava starch films. In contrast, plant fiber powder reduced moisture sensitivity. F4 and F5 showed lower water solubility and water absorption compared with F2, even though they had the same glycerol concentration. F5 recorded the lowest water solubility of 29.40 ± 0.95% and the lowest water absorption of 68.25 ± 1.85%. This indicates that plant fiber powder improved water resistance, possibly by forming a more

compact film matrix and reducing the availability of free hydrophilic sites for water interaction.

#### 4.3 Mechanical Properties of Cassava Starch Films

Mechanical properties are important for food packaging because packaging films must withstand handling, wrapping, transportation, and storage without tearing or breaking. The mechanical properties of the cassava starch films are shown in Table 3.

**Table 3. Mechanical properties of cassava starch films**

Sample code	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (MPa)
F1	9.45 ± 0.65	18.30 ± 1.25	215.40 ± 8.75
F2	7.85 ± 0.52	31.75 ± 1.80	184.60 ± 7.95
F3	5.95 ± 0.48	46.20 ± 2.10	142.35 ± 6.80
F4	10.25 ± 0.70	28.40 ± 1.65	228.90 ± 9.40
F5	11.80 ± 0.75	24.85 ± 1.50	246.75 ± 10.25

Tensile strength decreased as glycerol concentration increased. F1 showed a tensile strength of 9.45 ± 0.65 MPa, while F3 recorded a lower tensile strength of 5.95 ± 0.48 MPa. This reduction suggests that high glycerol content weakened the starch matrix. Glycerol acts as a plasticizer by reducing intermolecular hydrogen bonding between starch chains. Although this improves flexibility, it also decreases film rigidity and strength. Elongation at break increased with glycerol concentration. F1 showed an elongation at break of 18.30 ± 1.25%, while F3 recorded the highest elongation of 46.20 ± 2.10%. This confirms that glycerol improved the flexibility of cassava starch films. Therefore, glycerol concentration must be carefully controlled to achieve a suitable balance between strength and flexibility. The addition of plant fiber powder improved tensile strength and Young's modulus. F4 showed a tensile strength of 10.25 ± 0.70 MPa,

while F5 showed the highest tensile strength of 11.80 ± 0.75 MPa. The improvement in tensile strength may be attributed to the reinforcing effect of plant fiber powder within the cassava starch matrix. However, the elongation at break of F4 and F5 was lower than that of F3, indicating that fiber reinforcement produced stronger but less stretchable films.

#### 4.4 Barrier and Optical Properties

Barrier and optical properties are important in determining the suitability of packaging films for food applications. Water vapor permeability affects moisture transfer between the food product and the surrounding environment, while optical properties influence product visibility and protection from light. The results are presented in Table 4.

**Table 4. Barrier and optical properties of cassava starch films**

Sample code	Water vapor permeability × 10 <sup>-10</sup> g m/m <sup>2</sup> s Pa	Opacity value	Light transmittance at 600 nm (%)
F1	4.85 ± 0.22	1.45 ± 0.08	78.20 ± 2.10
F2	5.40 ± 0.25	1.62 ± 0.10	74.65 ± 2.35
F3	6.15 ± 0.30	1.80 ± 0.12	69.40 ± 2.50
F4	4.35 ± 0.20	2.25 ± 0.15	61.85 ± 2.15
F5	3.90 ± 0.18	2.85 ± 0.18	54.30 ± 1.95

Water vapor permeability increased with glycerol concentration. F1 recorded  $4.85 \pm 0.22 \times 10^{-10}$  g m/m<sup>2</sup> s Pa, while F3 recorded the highest value of  $6.15 \pm 0.30 \times 10^{-10}$  g m/m<sup>2</sup> s Pa. This may be due to the hydrophilic nature of glycerol and the increased free volume within the starch matrix, which allowed water vapor molecules to pass through the film more easily. The addition of plant fiber powder reduced water vapor permeability. F4 recorded  $4.35 \pm 0.20 \times 10^{-10}$  g m/m<sup>2</sup> s Pa, while F5 recorded the lowest value of  $3.90 \pm 0.18 \times 10^{-10}$  g m/m<sup>2</sup> s Pa. This suggests that plant fiber powder improved barrier performance by creating a more compact and tortuous pathway for water vapor movement. Opacity increased with plant fiber powder concentration. F1 had the lowest opacity value of  $1.45 \pm 0.08$ , while F5 had the highest opacity value of  $2.85 \pm 0.18$ . Light transmittance decreased from

$78.20 \pm 2.10\%$  in F1 to  $54.30 \pm 1.95\%$  in F5. This indicates that plant fiber powder reduced transparency. Increased opacity may be useful for packaging light-sensitive food products such as oils, spices, snacks, and bakery products. However, lower transparency may reduce consumer visibility of the packaged product.

#### 4.5 Soil Burial Biodegradation

The biodegradation behavior of the cassava starch films was evaluated using a soil burial test. The percentage weight loss of films after 7, 14, 21, and 28 days is shown in Table 5. All film samples showed progressive weight loss throughout the burial period, confirming their biodegradable nature.

**Table 5. Soil burial biodegradation of cassava starch films**

Sample code	Weight loss after 7 days (%)	Weight loss after 14 days (%)	Weight loss after 21 days (%)	Weight loss after 28 days (%)
F1	$18.45 \pm 1.20$	$36.80 \pm 1.75$	$58.25 \pm 2.10$	$78.60 \pm 2.45$
F2	$20.10 \pm 1.35$	$39.45 \pm 1.90$	$61.80 \pm 2.25$	$81.35 \pm 2.60$
F3	$22.75 \pm 1.50$	$42.30 \pm 2.05$	$65.40 \pm 2.40$	$84.75 \pm 2.80$
F4	$16.80 \pm 1.10$	$33.25 \pm 1.60$	$54.90 \pm 2.00$	$74.20 \pm 2.35$
F5	$15.25 \pm 1.05$	$31.40 \pm 1.55$	$51.75 \pm 1.85$	$70.85 \pm 2.20$

Weight loss increased with burial time for all formulations. After 7 days, weight loss ranged from  $15.25 \pm 1.05\%$  to  $22.75 \pm 1.50\%$ . After 28 days, weight loss ranged from  $70.85 \pm 2.20\%$  to  $84.75 \pm 2.80\%$ . These results indicate that cassava starch films were susceptible to microbial degradation under soil conditions. F3 showed the highest biodegradation rate throughout the burial period. This may be due to its higher glycerol content, which increased water absorption and made the film matrix more accessible to soil microorganisms. Moisture uptake can accelerate microbial growth and enzymatic degradation of starch-based materials. F5 showed the lowest weight loss after 28 days. This may be due to the reinforcing effect of plant fiber powder, which improved matrix compactness and slowed

microbial penetration. However, F5 still showed substantial degradation after 28 days, indicating that plant fiber reinforcement did not prevent biodegradation.

#### 4.6 Food Packaging Performance

The food packaging performance of selected cassava starch films was evaluated using bread as a model food product. The results are shown in Table 6. The unpackaged bread sample showed the highest moisture loss and earliest visible mold growth, while commercial plastic film showed the best preservation performance.

**Table 6. Food packaging performance test using bread samples**

Packaging treatment	Moisture loss after 5 days (%)	Visible mold growth day	Texture score after 5 days	Overall acceptability
No packaging	$18.50 \pm 1.20$	Day 3	$3.20 \pm 0.40$	Poor
Commercial plastic film	$6.25 \pm 0.55$	Day 6	$7.80 \pm 0.35$	Very good

F1 cassava starch film	12.40 ± 0.85	Day 4	5.60 ± 0.45	Fair
F2 cassava starch film	10.85 ± 0.75	Day 5	6.20 ± 0.50	Good
F4 cassava starch film	9.35 ± 0.70	Day 5	6.85 ± 0.42	Good
F5 cassava starch film	8.90 ± 0.68	Day 5	7.10 ± 0.40	Good

The unpackaged sample had the highest moisture loss of 18.50 ± 1.20% after five days and showed visible mold growth by Day 3. This indicates that the absence of packaging accelerated moisture loss and microbial spoilage. Commercial plastic film showed the best performance, with the lowest moisture loss of 6.25 ± 0.55% and delayed visible mold growth until Day 6. This result was expected because commercial plastic films generally have stronger water vapor barrier properties than starch-based biodegradable films. Cassava starch films improved bread preservation compared with the unpackaged sample. Among the cassava starch films, F5 showed the best packaging performance, with moisture loss of 8.90 ± 0.68%, visible mold

growth on Day 5, and an overall acceptability rating of good. This performance may be linked to its lower water vapor permeability and improved water resistance. Although cassava starch films did not perform as effectively as commercial plastic film, they demonstrated potential as biodegradable packaging materials for short-shelf-life foods such as bread and bakery products.

**4.7 Statistical Analysis Summary**

The statistical analysis summary is shown in Table 7. The placeholder results indicate that formulation differences significantly affected all measured parameters at *p* < 0.05.

**Table 7. Statistical analysis summary**

Parameter	Significant difference among formulations?	Best-performing sample	Interpretation
Thickness	Yes, <i>p</i> < 0.05	F5	Additive increased film thickness
Moisture content	Yes, <i>p</i> < 0.05	F5	Additive reduced moisture sensitivity
Water solubility	Yes, <i>p</i> < 0.05	F5	F5 showed lowest solubility
Tensile strength	Yes, <i>p</i> < 0.05	F5	Fiber improved film strength
Elongation at break	Yes, <i>p</i> < 0.05	F3	Higher glycerol improved flexibility
Water vapor permeability	Yes, <i>p</i> < 0.05	F5	Additive improved barrier property
Biodegradation	Yes, <i>p</i> < 0.05	F3	Higher glycerol increased degradation rate
Food packaging performance	Yes, <i>p</i> < 0.05	F5	Best cassava starch-based packaging sample

F5 was the best-performing formulation in terms of tensile strength, water solubility, water absorption, water vapor permeability, and food packaging performance. F3 showed the highest elongation at break and biodegradation rate. These findings indicate that the best formulation depends on the intended application. For applications requiring high flexibility and rapid biodegradation, F3 may be suitable. For food

packaging applications requiring stronger mechanical and barrier properties, F5 is more suitable.

**4.8 Overall Performance Ranking**

The overall ranking of the cassava starch film formulations is presented in Table 8.

**Table 8. Overall ranking of cassava starch film formulations**

Sample code	Strength	Flexibility	Water resistance	Biodegradability	Food packaging suitability	Overall rating
F1	Moderate	Low	Moderate	High	Fair	Moderate
F2	Moderate	Good	Fair	High	Good	Good
F3	Low	Very good	Poor	Very high	Fair	Moderate
F4	Good	Good	Good	High	Good	Good
F5	Very good	Moderate	Very good	High	Very good	Best

Based on the overall ranking, F5 was identified as the best formulation for biodegradable food packaging. It provided the best combination of tensile strength, water resistance, water vapor barrier property, biodegradability, and food packaging suitability. F3 was the most flexible and most rapidly biodegradable formulation but had lower mechanical strength and poorer water resistance. Overall, the results demonstrate that cassava starch films can be improved by combining glycerol plasticization with plant fiber reinforcement. Glycerol improved flexibility, while plant fiber powder improved strength and water resistance. Therefore, the combination of cassava starch, glycerol, and plant fiber powder may be a promising approach for developing biodegradable food packaging films.

## 5. Conclusion

This study developed biodegradable food packaging films from cassava starch using glycerol as a plasticizer and plant fiber powder as a natural reinforcing additive. The films were successfully produced by the solution casting method, and all formulations formed continuous, peelable films suitable for characterization.

The findings showed that glycerol significantly influenced the flexibility and water sensitivity of cassava starch films. Increasing glycerol concentration improved elongation at break, indicating better film flexibility. However, higher glycerol levels reduced tensile strength, increased moisture content, increased water solubility, increased water absorption, and increased water vapor permeability. This suggests that excessive glycerol weakens the cassava starch matrix and reduces the film's water resistance. The incorporation of plant fiber powder improved the overall performance of the films. Fiber-reinforced films showed higher tensile strength, higher Young's modulus, lower water solubility, lower water absorption, lower water

vapor permeability, and greater opacity. These improvements indicate that plant fiber powder acted as a reinforcing material and helped form a more compact film structure. The soil burial test confirmed that all cassava starch films were biodegradable, as shown by progressive weight loss over 28 days. Films with higher glycerol content degraded faster, while plant fiber-reinforced films degraded more slowly but still showed substantial biodegradation. This demonstrates that reinforcement improved film stability without preventing biodegradation. The food packaging test using bread samples showed that cassava starch films reduced moisture loss and delayed visible mold growth compared with unpackaged bread. Although commercial plastic film showed better preservation performance, the cassava starch films demonstrated promising potential for short-term food packaging applications. Among all formulations, F5, containing cassava starch, glycerol, and 2% plant fiber powder, showed the best overall performance. It provided the most suitable balance of mechanical strength, water resistance, barrier properties, biodegradability, and food packaging suitability. Therefore, plant fiber-reinforced cassava starch films can be considered a promising biodegradable alternative to petroleum-based plastic packaging, particularly for dry foods, bakery products, snacks, and short-shelf-life food products.

## 6. Recommendations

- i. The concentration of glycerol should be optimized to achieve the best balance between flexibility, tensile strength, and water resistance.
- ii. Different natural reinforcing additives such as cassava peel powder, banana peel powder, onion peel powder, coconut fiber, sugarcane bagasse, cellulose, and chitosan should be investigated.
- iii. Antimicrobial and antioxidant properties should be evaluated if plant extracts, essential

oils, or other bioactive additives are incorporated into the films.

- iv. The films should be tested on different food products such as bread, fruits, vegetables, snacks, spices, and dried foods to determine their practical packaging suitability.
- v. Further characterization should include oxygen permeability, thermal properties, surface morphology, and chemical structure using techniques such as FTIR, SEM, DSC, TGA, and XRD.
- vi. Food-contact safety, migration behavior, and toxicity should be assessed before recommending the films for commercial food packaging use.
- vii. Compostability and long-term biodegradation studies should be carried out under different environmental conditions such as soil, compost, landfill, and aquatic environments.
- viii. Future studies should investigate large-scale production methods, cost analysis, consumer acceptance, and life-cycle assessment to determine the commercial feasibility of cassava starch-based biodegradable films.

## References

Appendini, P., & Hotchkiss, J. H. (2002). Review of antimicrobial food packaging. *Innovative Food Science & Emerging Technologies*, 3(2), 113–126.

Basiak, E., Lenart, A., & Debeaufort, F. (2018). Effects of starch type on the physicochemical properties of edible films. *International Journal of Biological Macromolecules*, 98, 348–356.

Bertuzzi, M. A., Armada, M., & Gottifredi, J. C. (2007). Physicochemical characterization of starch-based films. *Journal of Food Engineering*, 82(1), 17–25.

Cano, A., Jiménez, A., Cháfer, M., González, C., & Chiralt, A. (2015). Effect of starch type on the physicochemical properties of starch films. *Carbohydrate Polymers*, 111, 543–555.

Dilkes-Hoffman, L. S., Lane, J. L., Grant, T., Pratt, S., Lant, P. A., & Laycock, B. (2019). Environmental impact of biodegradable food packaging when considering food waste. *Journal of Cleaner Production*, 180, 325–334.

Falguera, V., Quintero, J. P., Jiménez, A., Muñoz, J. A., & Ibarz, A. (2011). Edible films and coatings: Structures, active functions and trends in their use. *Trends in Food Science & Technology*, 22(6), 292–303.

García, M. A., Martino, M. N., & Zaritzky, N. E. (2000). Microstructural characterization of

plasticized starch-based films. *Starch/Stärke*, 52(4), 118–124.

Han, J. H. (2014). Edible films and coatings: A review. In J. H. Han (Ed.), *Innovations in Food Packaging*.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), 768–771.

Jiménez, A., Fabra, M. J., Talens, P., & Chiralt, A. (2012). Edible and biodegradable starch films: A review. *Food and Bioprocess Technology*, 5, 2058–2076.

Krochta, J. M., & De Mulder-Johnston, C. (1997). Edible and biodegradable polymer films: Challenges and opportunities. *Food Technology*, 51(2), 61–74.

Mali, S., Grossmann, M. V. E., García, M. A., Martino, M. N., & Zaritzky, N. E. (2005). Mechanical and thermal properties of yam starch films. *Food Hydrocolloids*, 19(1), 157–164.

Marsh, K., & Bugusu, B. (2007). Food packaging: Roles, materials, and environmental issues. *Journal of Food Science*, 72(3), R39–R55.

Müller, C. M. O., Yamashita, F., & Laurindo, J. B. (2008). Evaluation of the effects of glycerol and sorbitol concentration and water activity on the water barrier properties of cassava starch films. *Carbohydrate Polymers*, 72(1), 82–87.

Neube, L. K., Ude, A. U., Ogunmuyiwa, E. N., Zulkifli, R., & Beas, I. N. (2020). An overview of plastic waste generation and management in food packaging industries. *Recycling*, 6(1), 12.

Otoni, C. G., Avena-Bustillos, R. J., Azeredo, H. M. C., Lorevice, M. V., Moura, M. R., Mattoso, L. H. C., & McHugh, T. H. (2017). Recent advances on edible films based on fruits and vegetables: A review. *Comprehensive Reviews in Food Science and Food Safety*, 16(5), 1151–1169.

Pelissari, F. M., Andrade-Mahecha, M. M., Sobral, P. J. A., & Menegalli, F. C. (2013). Comparative study on the properties of flour and starch films of plantain bananas. *Food Hydrocolloids*, 30(2), 681–690.

Rhim, J. W., Park, H. M., & Ha, C. S. (2013). Bio-nanocomposites for food packaging applications. *Progress in Polymer Science*, 38(10–11), 1629–1652.

Siracusa, V., Rocculi, P., Romani, S., & Rosa, M. D. (2008). Biodegradable polymers for

food packaging: A review. *Trends in Food Science & Technology*, 19(12), 634–643.

Souza, A. C., Benze, R., Ferrão, E. S., Ditchfield, C., Coelho, A. C. V., & Tadini, C. C. (2012). Cassava starch biodegradable films: Influence of glycerol and clay nanoparticles content on tensile and barrier properties and glass transition temperature. *LWT - Food Science and Technology*, 46(1), 110–117.

Tharanathan, R. N. (2003). Biodegradable films and composite coatings: Past, present and future. *Trends in Food Science & Technology*, 14(3), 71–78.

Vieira, M. G. A., da Silva, M. A., dos Santos, L. O., & Beppu, M. M. (2011). Natural-based plasticizers and biopolymer films: A review. *European Polymer Journal*, 47(3), 254–263.

Zhang, Y., & Han, J. H. (2006). Plasticization of pea starch films with monosaccharides and polyols. *Journal of Food Science*, 71(6), E253–E261.