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# Assessment of the Biodegradation of Bioplastics from Cassava Starch and Glycerol in Kansanga-Kampala, Uganda

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## ABSTRACT

Plastics significantly contribute to environmental pollution due to their non-biodegradable nature. This study assesses the biodegradation of bioplastics derived from cassava starch and glycerol as an alternative to conventional plastics. Cassava starch was extracted using wet milling, followed by the formulation of bioplastic films with glycerol as a plasticizer. The chemical composition was analyzed using ATR-FTIR spectroscopy, confirming the presence of starch, glycerol, and cellulose derivatives. Biodegradability tests were conducted through soil burial and water degradation methods. Results showed that cassava starch-based bioplastics degraded completely within 10 days in soil, facilitated by microbial activity and moisture. In water, a 60% weight loss was observed over 14 days due to hydrolysis. The presence of hydroxyl and carbonyl functional groups contributed to the film's hydrophilic nature, accelerating degradation. These findings suggest that cassava starch-based bioplastics offer a viable and environmentally friendly alternative to petroleum-based plastics. However, further optimization of mechanical properties and water resistance is recommended to enhance practical applications in packaging and other industries.

**Keywords:** Cassava starch-based bioplastics; Biodegradability; ATR-FTIR spectroscopy; Soil and water degradation; Environmental pollution

## INTRODUCTION

Plastics are used extensively in industrial and household products. Plastics are commonly used in a variety of applications, including hand baggage, bottles, toys, packaging, electronic equipment components, car modules, office block segments, furniture, and textile materials [1, 2]. Although plastics have improved our lives considerably, they now threaten our environment and our health through their associated carbon emissions and persistence in the ecosystems as waste. Plastic bag manufacturing emits harmful gases, including carbon, which raises environmental concerns. According to the National Environment Management Authority, Uganda has generated about 12,330 metric Tonnes of PET plastic since 2018. The Kampala Metropolitan Area generates 135,804 Tonnes of plastic garbage each year. Of this, 42% is uncollected, 15% is collected via the value chain approach, and 43% is collected by service providers. Approximately 21,728T of plastics are burned, 47,457T are landfilled/dumped, 27,160T are retained on land, and 13,580T enter water systems. NEMA also states that as a result of plastic pollution, the country is experiencing an increase in unexplained cancers, floods, poor water quality, poor air quality, decreased soil fertility, siltation of water bodies [3], the death of livestock, fish, and wildlife due to ingestion and entanglement, and, most importantly, increased greenhouse gas emissions. Allegedly, the first plastic sample ever made has still not degraded, yet an end-of-life can be identified for products even without degradation. Plastics can be recycled, landfilled, or end up in the environment with or without modification. In 2013, 32 % of the 78 million Tonnes of plastics produced ended up in the environment [3, 4].

Waste management is a major socioeconomic and governmental concern, especially in cities faced with high population growth and waste production. Uncollected and untreated waste has social and environmental implications that reach beyond the city limits. The environmental sustainability implications of poor waste management include methane (CH4) emissions, bad odors, air pollution, land and water contamination, and an increased number of rodents, insects, and flies that spread diseases to humans [5–7].

Several global development goals, agreements, and visions highlight the necessity of waste management in achieving the United Nations' Sustainable Development Goals. For example, sustainable waste management can help achieve numerous SDGs, such as ensuring clean water and sanitation (SDG 6), municipal solid waste management (SWM) (SDG 11.6.1), food loss and waste (SDG 12.3.1), information transmitted under chemicals and waste conventions (SDG 12.4.1), hazardous waste generated and treated (SDG 12.4.2), national recycling rate (SDG 12.5.1), mitigating climate change (SDG 13), and protecting life on land (SDG 15). Many low-income developing countries collect only 10% of the trash produced in suburban areas, contributing to public environmental and health risks such as increased incidences of diarrhea and serious respiratory illnesses among people living near trash dumps, particularly children. Efficient municipal trash management is hampered by a lack of expertise, technology, funding, and strong governance [8, 9].



In Uganda, plastic garbage is commonly disposed of by open incineration, landfilling, and indiscriminate dumping on roadsides and sewers without collection. Plastics do not biodegrade and remain in the soil, leading to soil degradation by preventing water infiltration. When plastics are not removed from the soil, they seep into groundwater and eventually make their way into water bodies like lakes, rivers, and oceans, resulting in water pollution. The plastics eventually get consumed by the fish we eat. One in every five fish in Lake Victoria has been found to have ingested plastic. Animals and aquatic organisms such as fish, birds, and turtles have reportedly died from ingesting or getting entangled in plastic debris [10].

Plastic waste incineration emits halogenated additives, polyvinyl chloride, furans, dioxins, and polychlorinated biphenyls (PCBs) into the environment. One drawback of burning plastics is the discharge of harmful vapours into the atmosphere, leading to air pollution [11, 12]. Consumption and disposal of single-use plastics are global issues. Plastic, a petrochemical product derived from crude oil, can take 100 to 500 years to disintegrate, taking up a large amount of space in landfills and oceans. Fueled by a growing single-use consumer base, the rate at which plastics are manufactured and disposed of is exceeding most other man-made materials, causing significant environmental repercussions [13, 14]. The implementation of new environmental legislation and increased environmental awareness have prompted the hunt for environmentally friendly products.

Bioplastics have received a lot of attention as a way to build a sustainable ecosystem because of their biodegradability. Biodegradable plastics, also known as bioplastics, are made from renewable biomass, such as starch, cellulose, collagen, polylactic acid, and polyester amides [15, 16] . They are produced from renewable materials such as plants and animal matter.

To be specific, there are biodegradable plastics and bio-based plastics. The former are plastics that can be assimilated by bacteria and fungi to give environmentally friendly products, while the latter are plastics that are made from renewable sources such as biomass or waste [17].

Biodegradability does not only depend on the origin of the materials, that is to say, plants and animals, it depends on the properties of the plastic such as chemical structure and crystallinity. Some petro-based plastics are considered biodegradable since they can be broken down by microorganisms into useful materials under suitable conditions[17]. Bio-based plastics are biodegradable since they are made from renewable resources and when broken down, can be useful to their environment. Examples of biodegradable plastics include starch-based plastics, polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (PBS), cellulose-based plastics, polycaprolactone (PCL) and many others.

Although bioplastics are thought to be environmentally beneficial, they do have significant drawbacks, including high production costs and poor mechanical qualities such as low tensile strength. The high cost of production can be countered by utilizing low-cost renewable resources such as agricultural waste for example, cassava, yams, sweet potatoes, maize, rice and other starch-containing plants [18, 19]. The production process, therefore incorporates additives such as plasticizers like glycerine to improve the properties of the bags without affecting the biodegradability of the product when disposed in the environment.

Scientific data on the biodegradation of commercial bioplastics are still not extensive, making it difficult to draw definitive conclusions about bioplastic waste behavior [20]. Commercial bioplastics are mainly made by combining biopolymers with plasticizers and additives, which increase their physical and mechanical properties, but also impact their biodegradability and may lead to the formation of some unwanted final products or degraded wastes [21]. Given this background, this study aims to contribute to the knowledge of how bioplastic films, specifically cassava starch-based bioplastic degrades in the natural environment and what components aid in this biodegradability.

In Uganda today, almost every household and commercial establishment uses plastics, which after disposal have negative effects on the environment. As a result of increasing population in the country, the need for use of plastics in daily life such as for packaging has also increased hence increasing the impact of the plastics on the environment on disposal for example flooding caused by blocking of drainage systems by plastics, water and land pollution, air pollution from fumes released by burning of plastics that is to say Carbon dioxide, carbon monoxide and other gases emitted which leads to global warming. Conventional plastics are composed of non-biodegradable polymers such as polyethene and polypropylene whereby once used and deposited in the environment, cannot be broken down by microorganisms in the natural environments. Plastic bag waste is either collected and incinerated at designated garbage points in an open environment or burned at unapproved places, sometimes plastic waste is sent to landfills or disposed in water bodies hence leading to accumulation in the environment and the subsequent effects.

Therefore, this research intends to mitigate the pollution caused by plastic bags by evaluating the possibility of developing biodegradable film from cassava starch as the main ingredient, focusing on the viability of the ingredients and their properties to provide alternative packaging solutions. The objective of this study was to evaluate the biodegradability of cassava starch-based bioplastics in various natural environments, including soil and water. Specifically, the study aims to extract starch and characterize the chemical components of cassava starch-based bioplastics, determine their biodegradability in soil by measuring the percentage loss in mass, and assess their biodegradation in water through the evaluation of mass loss.



## METHODOLOGY

The materials used in the formulation of the cassava starch-based bioplastic were cassava starch, distilled water, glycerol and acetic acid glacial (for analysis). The tools used in the procedure were analytical balance, beakers, conical flasks, oven, stirrer, knife, grater, motor and pestle.

### 2.1 Sampling

The research followed random sampling technique where cassava tubers were purchased in Kansanga market, washed and prepared for extraction of starch.

### 2.2 Materials and preparation of starch and Bioplastic

#### *2.2.1 Description of Cassava starch and glycerol*

Starch ($(C_6H_{10}O_5)_n$), also known as tapioca, is a natural reserve component present in plant seeds, tubers, and roots. Starch is a polysaccharide composed of glucose monomers and its two main polymers are: amylose (linear) and amylopectin (branched). Starch is renewable, readily biodegradable, easily modified and available in bulk in all parts of the world at low cost [22, 23]. Cassava starch granules are spherical, with truncated terminals and a clearly discernible nucleus (thread). Size ranges from 5 to 35μm, with an average of 15–18μm. Starch physicochemical properties include proximal composition, granule size and shape, crystalline nature, molecular weight, swelling power, solubility, relative amylose content, and paste characteristics. Cassava starch gelatinizes in water at temperatures over 60°C. However, at temperatures above 90°C, the paste viscosity decreases dramatically with continuous solubilization and agitation, and no gel forms with subsequent cooling [24]. The physicochemical properties of cassava starch are what make it a suitable ingredient for making biodegradable plastics. Once starch powder is mixed in water and heated, it swells and gelatinizes to form the base biopolymer for biodegradable plastics.

A combination of glycerol-acetic acid was used as a plasticizer for the biodegradable plastic. Glycerol ($C_3H_8O_3$) is a colorless, odorless, viscous and hygroscopic liquid. Acetic acid, also known as ethanoic acid, is a weak organic acid with a characteristic sour smell and taste with the chemical formula of $CH_3COOH$. When used alone as a plasticizer, glycerol tends to migrate from the film matrix at times, hence the addition of acetic acid to ensure cohesive film formation. Plasticizers are added to increase the flexibility and usability of starch-based bioplastics. Starch cannot be melted in its natural form because of the strong hydrogen bonds; instead, plasticizer molecules penetrate starch granules and weaken hydrogen bonds under high temperatures, pressures, and shear stress [25].

#### *2.2.2 Procedure for bioplastic formulation*

Extraction of cassava starch was done by wet milling process. Cassava tubers were purchased from Kansanga market and washed to remove dirt and soil. The cassava tubers were peeled, sliced into pieces and grated in a dish. The grated pieces were washed with water and the water was filtered off. The cassava pieces were soaked in distilled water for 8 to 10 hours to extract starch. The mixture was filtered, and the starch was allowed to settle at the bottom of the container for 4 to 8 hours. The water was decanted to obtain the starch at the bottom after 8 hours. Starch was dried under the sun for 8 hours in an open container[26].

The cassava starch-based bioplastic film was made by weighing 8g of starch powder and put in a conical flask. 100ml of distilled water were added and the mixture was stirred thoroughly to dissolve the starch powder. 4ml of glycerol and 4ml of acetic acid were added to the mixture and stirred. The solution was immediately heated to about 60°C-70°C until it formed a gel substance. The resulting gel mixture was poured onto aluminum foil, placed on a tray and dried in an oven at around 70°C for approximately 8 hours to obtain the bioplastic film[27]

### 2.3 Experimental set-up

#### *2.3.1 ATR-FTIR spectroscopy*

Attenuated Total Reflectance- Fourier Transform InfraRed (ATR-FTIR) spectroscopy was used for the chemical analysis to identify the major components, functional groups and interaction of the group with other parts of the molecule present in the bioplastic film [28]. In particular, the SHIMADZU ATR-FTIR model: IRTracer- 100 was used in the analysis. This technique works by measuring the interaction of infrared light with a sample to identify its molecular composition. When the light hits the interface between the crystal and the sample, it undergoes reflection, and the sample absorbs specific wavelengths depending on the molecular bonds and structure. The absorbed light is detected and transformed into a spectrum. The spectrum represents a fingerprint of the sample with absorption peaks that correspond to the frequencies of vibrations between the bonds of the atoms making up the material. This technique was selected because it is non-destructive and provides a precise measurement method that requires no external calibration.

***2.3.2 ATR-FTIR procedure and analysis of the sample***

The ATR-FTIR machine and computer were switched on and a background (BKG) scan was run to set parameters:



i) Number of scans at 20.
ii) Resolution at 4.
iii) Spectrum range at Minimum= 400 $cm^{-1}$ and maximum= 4500 $cm^{-1}$.
iv) Measurement mode by transmittance.

After running the background scan and obtaining a spectrum, the adjustment knob on the ATR compartment was adjusted and the ATR crystal surface was cleaned with ethanol and a soft tissue. The bottom of the pointer of the adjustment knob was also cleaned and a piece of the sample was placed on the crystal surface. The sample was held in position by the knob pointer and measured by clicking "Sample Scan" on the computer software. A sample spectrum was displayed on the monitor after completing 20 scans. A spectrum search was conducted from the library, and a matching spectrum of soluble starch was obtained. The results were saved as BIO FILM 3. The adjustment knob was turned to raise the pointer and the sample was removed. The ATR crystal surface was cleaned using a soft tissue. The results, obtained in the form of a spectrum, were used to relate the presence of these components to the biodegradability of the cassava starch-based bioplastic films formed.

**2.4 Biodegradability testing methods**

Biodegradability tests were done by the soil burial method and moisture absorption to determine how much of the bioplastic film would be degraded in a home environment, considering environmental temperatures of between 19°C - 30°C. The relationship between the biodegradation process and the abundance of microorganisms in soils facilitates a more dependent and desired bioplastic degradability study than in other environments. Degradation testing determines the level of breakdown of bioplastics. The degradation can be detected in the reduction of mass of the samples buried in the soil.

***2.4.1 Soil burial method***

Bioplastics were cut into 2 cm x 2 cm. Then, they were buried in a soil mixture consisting of soil, plant waste, plant waste, insects, worms and water. The soil mixture was poured into a plastic dish up to 4 cm high. A 2 × 2 cm film was weighed and buried to a depth of 2 cm. The plastic dish was placed under environmental temperature and humidity conditions. The burial duration varied (3, 6, and 10 days). Before burial, the original mass (mass before degradation) was determined. The final mass (mass after degradation) of the bioplastic film was then measured. Any observable changes in physical features resulting from the deterioration process were noted and when the bioplastics were entirely decomposed, the degradation percentage (weight loss) was calculated by the equation [29].

Degradation (%) = (wi − wf)/wi × 100

where wf = final weight after degradation, wi = initial weight before degradation.

***2.4.2 Water degradation and swelling test***

**Water degradation**

The degradation of the sample in water involved immersing a 2×2cm bioplastic film in 200ml of water at room temperature for a period of 14 days. The original mass of the film was measured. The final mass after 14 days was also measured by filtering and obtaining the weight of the residue.

Degradation (%) = (wi − wf)/wi × 100

where wf = final weight after degradation, wi = initial weight before degradation.

**Swelling test**

The swelling capability of starch-based bioplastic film was tested in water. The dry sample was cut from the bioplastic film (2 x 2 cm), weighed, and immersed in water at 25°C for 24 hours. The sample was extracted, dried, and weighed again. The swelling capacity was determined using the equation below (Othman *et al.*, 2017).

Swelling (%) = (wf − wi)/wi× 100

where wf = final weight after swelling, wi = initial weight before swelling.

**RESULTS**

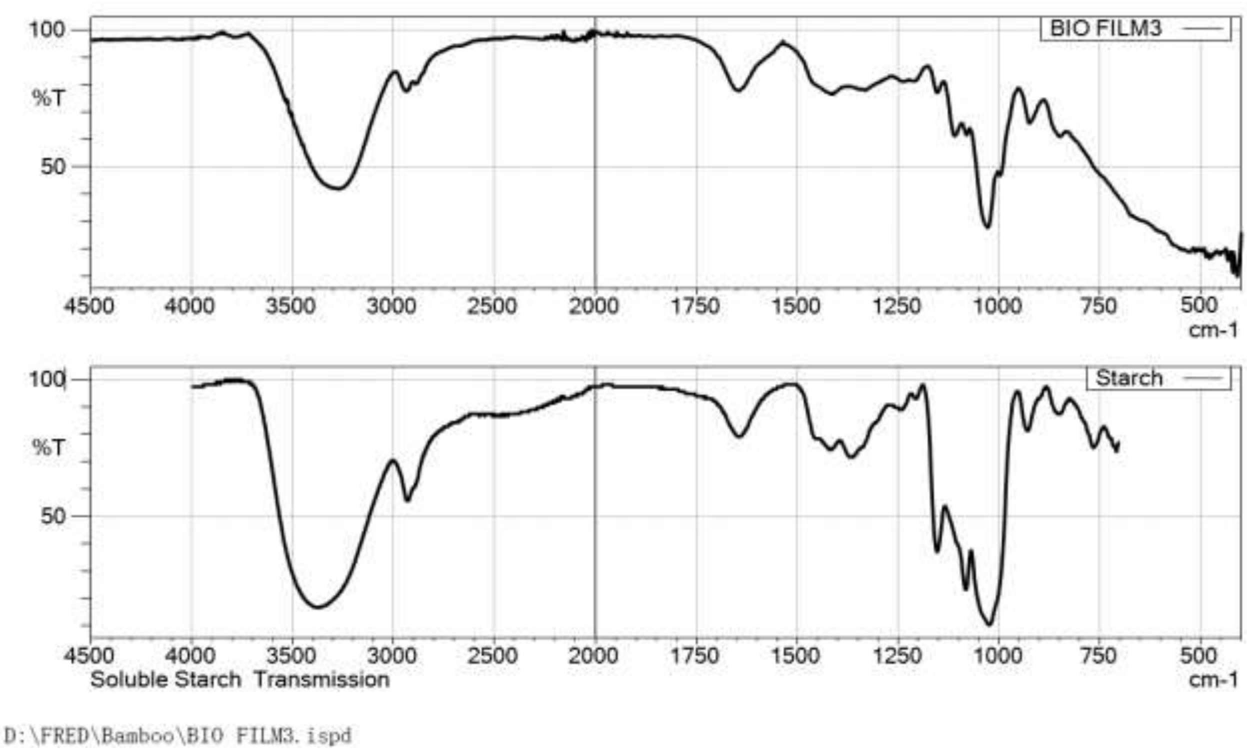


**Figure 1: FTIR spectrum for cassava starch-based biofilm 3**

**Table 1: Results from FTIR spectrum analysis**

| | Score | Library | Name | Comment |
|---|---|---|---|---|
| **1** | 854 | 4 - T-Organic2 | Starch | Soluble Starch Transmission |
| **2** | 796 | 100 - IRs ATR Reagent2 | 100 | Glycerol $CH_2(CH)CH(OH)CH_2OH$ ATR/diamond molecular weight:92.10 liquid |
| **3** | 757 | 50 - A_FoodAdditives2 | A-Powdered Cellulose-4 | Powdered Cellulose (Product name; VITACEL L-600CSales origin; TOAKASEI CO.LTD) @DuraSamplIR2(diamond) |
| **4** | 757 | 29 - ATR-Organic2 | D-Ethylene-Glycol | Ethylene-Glycol Dura SampllR |
| **5** | 754 | 42 - A_FoodAdditives2 | A Micro-fibrillated Cellulose_100F-4 | Micro-fibrillated Cellulose (Product name; CELISH FD-100FCSales origin; Daicel Chemical Industries Ltd.) @DuraSamplIR2(diamond) |
| **6** | 751 | 44 - A_FoodAdditives2 | A-Micro-fibrillated Cellulose_200L-4 | Micro-fibrillated Cellulose (Product name; - CELISH FD-200LCSales origin; Daicel Chemical Industries Ltd.) @DuraSamplIR2(diamond) |
| **7** | 749 | 8 - ATR-Polymer2 | D_Cellulose2 | Paper DuraSamplIR-II |
| **8** | 748 | 11 - T-Inorganic2 | Na3PO4 | $Na_3PO_4$ $12H_2O$ Transmission |
| **9** | 736 | 40 - A_FoodAdditives2 | A-Microcrystalline Cellulose_101-4 | Microcrystalline Cellulose (Product name; VIVAPUR101CSales origin; TOAKASEI CO.LTD) @DuraSamplIR2(diamond) |
| **10** | 735 | 43 – A-FoodAdditives2 | A- Micro-fibrillated Cellulose_100G-4 | Micro-fibrillated Cellulose (Product name; CELISH FD-100GCSales origin; Daicel Chemical Industries Ltd) @DuraSamplIR2(diamond) |
| **11** | 734 | 41 -A-FoodAdditives2 | A-Microcrystalline Cellulose_102-4 | Microcrystalline Cellulose (Product name; VIVAPUR102CSales origin; TOAKASEICO.LTD) @ DuraSamplIR2(diamond) |
| **12** | 733 | 174 - ATR-Polymer2 | D-Tencel | Tencel (LENZING Corporation) DuraSamplIR-II |
| **13** | 732 | 11 - ATR-Polymer2 | D-Cellulose4 | Bemberg (Cupra) DuraSamplIR-I |
| **14** | 728 | 143 - T-Polymer2 | T-Tencel | Tencel (LENZING Corporation) Transmission (Microscope) |
| **15** | 727 | 31 - ATR-Organic2 | D-Propylene-Glycol | Propylene-Glycol DuraSampllR |
| **16** | 724 | 12 - T-Polymer2 | Ramie | Ramie Transmission (Microscope) |
| **17** | 723 | 4 - ATR-Organic2 | D-Starch | Soluble Starch DuraSampllR |
| **18** | 721 | 11 - T-Polymer2 | Cupra | Bemberg (Cupra) Transmission (Microscope) |
| **19** | 720 | 8 - T-Polymer2 | Paper | Paper Transmission (Microscope) |
| **20** | 717 | 8 - IRs Polymer2 | CELLOPHA | Cellulose ATR/diamond ATR-corrected |

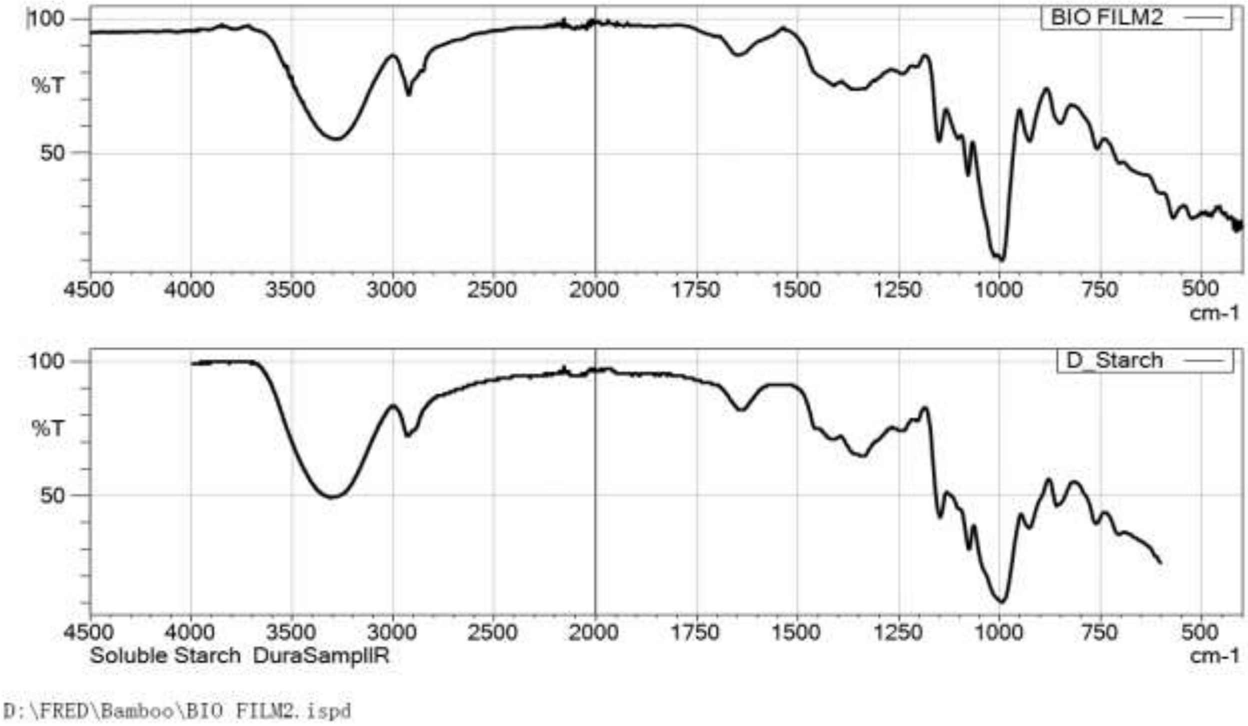


**Figure 2: FTIR spectrum for cassava starch-based biofilm 2**

**Table 2: Results from FTIR spectrum analysis**

| | Score | Library | Name | Comment |
|---|---|---|---|---|
| **1** | 946 | 4 - ATR-Organic2 | D-Starch | Soluble Starch DuraSampllR |
| **2** | 838 | 4 - T-Organic2 | Starch | Soluble Starch Transmission |
| **3** | 816 | 111 - IRs ATR Reagent2 | 111 | Dextran 2000 ($C_6H_{10}O5$) n ATR/diamond molecular weight:180000`210000 powder |
| **4** | 814 | 231 - IRs ATR Reagent2 | 231 | beta-Cyclodextrin ($C_6H_{10}O5$)7 ATR/diamond molecular weight:1135.00 powder |
| **5** | 812 | 122 - IRs ATR Reagent2 | 122 | Carminic Acid $C_{22}H_{20}O13$ ATR/diamond molecular weight:492.39 powder |
| **6** | 805 | 11 - ATR-Polymer2 | D_Cellulose4 | Bemberg (Cupra) DuraSamplIR-I |
| **7** | 800 | 230 - IRs ATR Reagent2 | 230 | alpha-Cyclodextrin ($C_6H_{10}O_5$)6ATR/diamond molecular weight:972.85 powder |
| **8** | 798 | 8 - IRs Polymer2 | CELLOPHA | Cellulose ATR/diamond ATR-corrected |
| **9** | 798 | 174 - ATR-Polymer2 | D-Tencel | Tencel (LENZING Corporation) DuraSamplIR-II |
| **10** | 789 | 165 - IRs ATR Reagent2 | 165 | Soluble Starch ATR/diamond molecular weight: powder |
| **11** | 781 | 6 - ATR-Organic2 | D-Glucose | D (+)-Glucose DuraSampllR |
| **12** | 756 | 11 - ATR-Inorganic2 | D_$Na_3PO_4$ | $Na_3PO_4$ $12H_2O$ DuraSampllR |
| **13** | 751 | 50 - A_FoodAdditives2 | A-Powdered Cellulose-4 | Powdered Cellulose (Product name; VITACEL L-600CSales origin; TOAKASEI CO.LTD) @DLraSamplIR2(diamond) |
| **14** | 744 | 27 - ATR-Inorganic2 | D_TALC2 | TALC (with Polyethylene, Chlorinated /Chlorine content 25%) DuraSamplIR-II |
| **15** | 739 | 5 - IRs Polymer2 | BEMBERG | Bemberg (Cupra) Fiber ATR/diamond ATR-corrected |
| **16** | 739 | 30 - ATR-Inorganic2 | D_TALC4 | TALC (Polyethylene, Chlorinated/Chlorine content 48%) DuraSamplIR-II |
| **17** | 731 | 19 - A_FoodAdditives2 | A-Carboxymethyl Cellulose Calcium-4 | Carboxymethyl Cellulose Calcium (Product name; E.C.G-FAC Sales origin; Gotoku CHEMICAL CO.LTD.) @ DuraSamplIR2 (diamond) |
| **18** | 730 | 43 - A_FoodAdditives2 | A-Micro-fibrillated Cellulose_100 G-4 | Micro-fibrillated Cellulose (Product name; CELISH FD100GC Sales origin; Daicel Chemical Industries Ltd.) @DuraSamplIR2 (diamond) |
| **19** | 723 | 11 - T-Inorganic2 | $Na_3PO_4$ | $Na_3PO_4$ $12H_2O$ Transmission |
| **20** | 723 | 3 - T-Inorganic2 | TALC | TALC/$3Mg_4SiO_2H_2O$ Transmission |

## DISCUSSION

From the spectrum for the biofilm with glycerol, the spectral analysis of the biofilm sample revealed that it is primarily composed of starch, glycerol, and cellulose derivatives. The biofilm's composition is characterized by transmittance peaks aligning with starch, glycerol, and cellulose derivatives. The data also contains peaks in the 400-4500 $cm^{-1}$ range, corresponding to the functional groups in the biofilm. The combination and relative areas of peaks across the whole spectral range assist in determining the structure and identity of polymers during library searches. It is also possible to investigate individual peaks. The large peaks in the 3000-3600 wave number range are mostly caused by stretching of the O-H bond, which is typically associated with material hydration. The double peaks at 2940 and 2886 are caused by stretching of C-H bonds, which is noticeable in most organic compounds [30]. The presence of these functional groups represents the interaction between starch and glycerol during the formation of the bioplastic. The biofilm's components were identified based on similarity scores, with the highest scores indicating the presence of soluble starch, a plasticizer that improves film flexibility by reducing brittleness. Other components included powdered cellulose, ethylene glycol, micro-fibrillated cellulose, microcrystalline cellulose, and regenerated cellulose fibers.

The biofilm's functional properties include flexibility due to glycerol, strength due to cellulose and micro-fibrillated cellulose, biodegradability due to its composition mainly of starch and cellulose-based materials, and water sensitivity due to the hydrophilic nature of glycerol and starch. The biofilm has potential applications in biodegradable packaging, food coatings, and other environmentally friendly materials. The IR analysis confirms that the biofilm is primarily composed of starch, glycerol, and cellulose derivatives, with glycerol improving its flexibility and cellulose contributing to strength. This composition makes it suitable for biodegradable applications.



The biofilm is primarily composed of starch and cellulose derivatives, making it likely biodegradable. The highest match score (854) is for soluble starch, suggesting that the biofilm contains starch-based materials. Cellulose-based materials are identified in various forms, such as cellophane, Bemberg, powdered cellulose, micro-fibrillated cellulose, and Carboxymethyl cellulose calcium. Cyclodextrins and other modified starch derivatives were identified, such as beta-cyclodextrin (814 score) and alpha-cyclodextrin (814 score). Cyclodextrins are often used to enhance the properties of biopolymers, including solubility, stability, and biodegradability. Inorganic components like sodium phosphate ($Na_3PO_4 \cdot 12H_2O$) and talc (scores: 744, 739, 723) are likely used as buffers or stabilizers, while glucose (781 score) is a simple sugar and carminic acid (812 score) is a natural dye. These organic substances could indicate natural additives or impurities present in the biofilm.

The figures below display the reduction in mass of bioplastics over 3, 6, and 10 days. The mass of bioplastics buried for six days was reduced by more than half. This mass loss occurred because the bioplastics were made of natural components that were easily eaten by microorganisms. Bioplastics degraded into fragments in 7 days but reached total disintegration on the tenth day. After absorbing water from the soil, the hydroxyl group in cassava starch triggered the hydrolysis reaction, which resulted in cassava starch being decomposed into small pieces and rapidly disappearing. A high concentration of glycerol in bioplastics resulted in rapid reduction in mass. Bioplastics are an eco-friendly packaging material because of their hydrophilic nature, which allows them to breakdown readily in the environment. Therefore, presence of microorganisms and water/ moisture are the key factors that influence the breakdown of bioplastics in soil.

Degradation (%) = (wi − wf)/wi × 100

where wf = final weight after degradation, wi = initial weight before degradation.

Wi = 2.0g

Wf = 0.0g

Degradation % = (2.0- 0.0)/ 2.0 × 100

= 100%

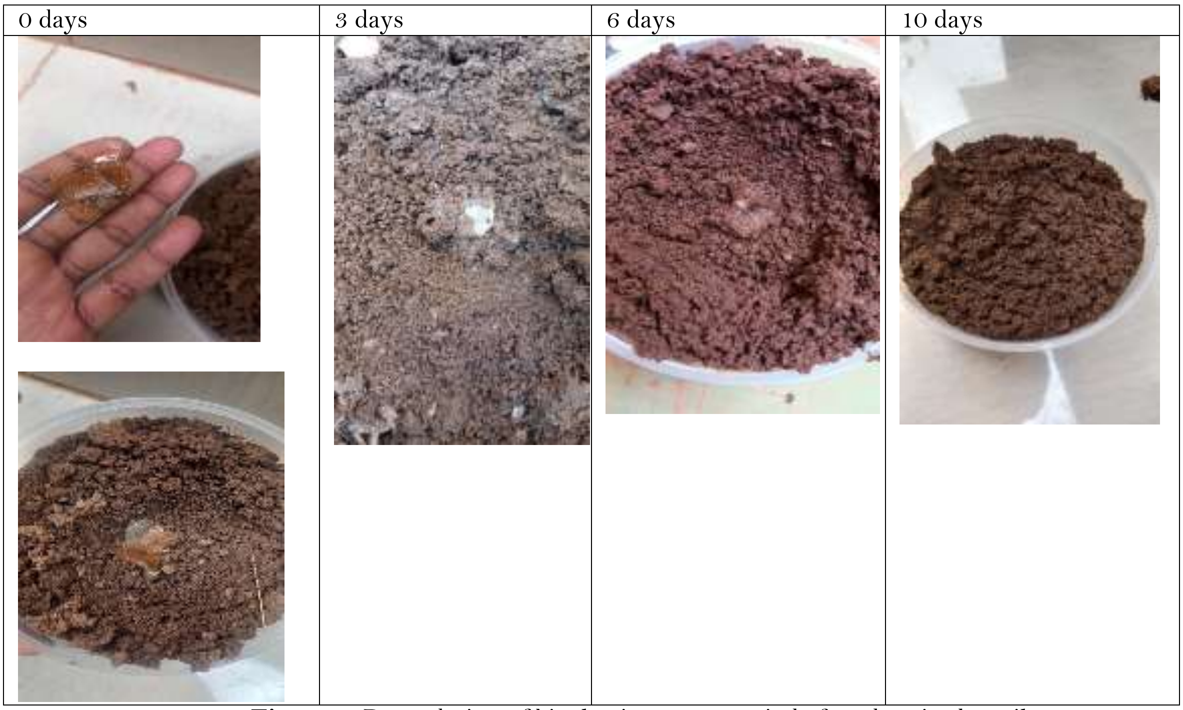


**Figure 3**: Degradation of bioplastics over a period of 10 days in the soil

**Water degradation and swelling test**

The figure shows that the bioplastic film partially disintegrated in water over a period of 24 hours by losing some of its physical characteristics. This is because bioplastic film exhibits hydrophilic properties associated with glycerol and starch. These properties increase the affinity between glycerol and water, hence the increase in water absorption. The fact that cassava starch bioplastic contains hydroxyl (OH), carbonyl (CO), and ester (COOH) functional groups, as indicated by the different peaks in the FTIR spectrum, when the concentration of hydrophilic properties in the bioplastics is high, degradation in the soil is expected to also increase.



**Water degradation**

The mass of bioplastics immersed in water for 14 days was measured. The mass loss occurred because the bioplastics were made of hydroxyl groups that triggered the hydrolysis reaction, which resulted in the bioplastic film being decomposed into small pieces and rapidly disappearing. A high concentration of glycerol in bioplastics resulted in rapid reduction in mass.

Degradation (%) = $(wi - wf)/wi \times 100$

where wf = final weight after degradation, wi = initial weight before degradation.

Wi= 2.0g

Wf = 0.8g

Degradation percentage = $(2.0 - 0.8)/ 2.0 \times 100$

=60%

**Swelling test**

Swelling (%) = $(wf - wi)/wi \times 100$

where wf = final weight after swelling, wi = initial weight before swelling.

Wi = 1.0g

Wf = 1.4g

Swelling percentage = $(1.4 - 1.0)/ 1.0 \times 100$

= 40%

**Figure 4: water absorption and swelling tests**

The biofilm is primarily composed of starch and cellulose derivatives, making it likely biodegradable. The presence of cyclodextrins suggests potential modifications to enhance material performance. Inorganic components like $Na_3PO_4$ and talc may serve as stabilizers or reinforcements, and the identification of glucose and carminic acid may hint at the biological origin or processing of the material. The majority of bacteria and microorganisms, especially those found in soil, live in water. As a result, higher water content causes polymers to break down more easily. The higher the concentration of glycerol, the more water can infiltrate the structure of bioplastics and aid in biological/microbial activities. The higher the glycerol and starch content, the more easily it degrades. The degradation process then proceeds by widening the surface through erosion and perforation; these methods may accelerate the breakdown because the holes created facilitate the transport of oxygen and enzymes into the bioplastics.

## CONCLUSION



The biofilm is primarily composed of starch and glycerol, making it likely biodegradable. The highest match score (854) is for soluble starch, suggesting that the biofilm contains starch-based materials. Cellulose-based materials are identified in various forms, such as cellophane, Bemberg, powdered cellulose, micro-fibrillated cellulose, and Carboxymethyl cellulose calcium. Cyclodextrins and other modified starch derivatives were identified, such as beta-cyclodextrin (814 score) and alpha-cyclodextrin (814 score). Cyclodextrins are often used to enhance the properties of biopolymers, including solubility, stability, and biodegradability.

Inorganic components like sodium phosphate ($Na_3PO_4 \cdot 12H_2O$) and talc (scores: 744, 739, 723) are likely used as buffers or stabilizers, while glucose (781 score) is a simple sugar and carminic acid (812 score) is a natural dye. These organic substances could indicate natural additives or impurities present in the biofilm. In conclusion, the biofilm is primarily composed of starch and cellulose derivatives, making it likely biodegradable. The presence of cyclodextrins suggests potential modifications to enhance material performance. Inorganic components like $Na_3PO_4$ and talc may serve as stabilizers or reinforcements, and the identification of glucose and carminic acid may hint at the biological origin or processing of the material.

## RECOMMENDATIONS

The biofilms analyzed in this study have shown strong potential for use in biodegradable packaging, agricultural applications, and eco-friendly materials. To expand their usability in commercial industries, further optimization of plasticizer content, water resistance, and mechanical strength is recommended. Experimental trials should focus on improving durability while maintaining sustainability, making these biofilms a viable alternative to petroleum-based plastics. The biofilm composition analyzed includes starch, glycerol, dextran, cellulose, cyclodextrins, carminic acid, glucose, and various inorganic additives such as talc and sodium phosphate. These results indicate that the biofilm has potential applications in various fields, including biodegradable packaging, agriculture, biomedical uses, and industrial applications.

To improve its mechanical, functional, and environmental performance, several recommendations are proposed. First, the biofilm should be optimized for flexibility and tensile strength by incorporating plasticizers such as glycerol, sorbitol, or propylene glycol. Second, the biofilm should be strengthened with fillers, such as micro-fibrillated cellulose and carboxymethyl cellulose calcium, nano-cellulose or chitosan, and identified talc components. Third, the biofilm should be improved for barrier properties, reducing water sensitivity by using hydrophobic coatings, chemical cross-linking using citric acid or boric acid, and enhancing oxygen and gas barrier properties by incorporating lipid-based coatings or clay nanocomposites. Further exploration of industrial and environmental applications is also suggested. The polysaccharide-rich composition of the biofilm makes it a promising alternative to petroleum-based plastics. Further biodegradability and compostability studies should be conducted to assess degradation rates in soil, water, and industrial composting settings. Food packaging requires additional food safety and migration testing to ensure no harmful compounds leach into food products.

Agricultural applications, such as mulching films and drug delivery systems, could benefit from the biofilm's moisture retention and biodegradability. Further experimental testing and optimization are recommended, including tensile strength, moisture absorption, permeability, UV stability, thermal degradation, and eco-toxicity studies. In conclusion, the biofilm's performance, sustainability, and commercial viability will be enhanced by optimizing its mechanical, functional, and environmental properties.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ATR-FTIR | Attenuated Total Reflectance- Fourier Transform InfraRed |
| ASTM | American Society for Testing and Materials |
| BKG | Background |
| ISO | International Organization for Standardization |
| IUPAC | International Union of Pure and Applied Chemistry |
| NEMA | National Environment Management Authority |
| PBAT | Polybutylene Adipate Terephthalate |
| PBS | Polybutylene Succinate |
| PCB | Polychlorinated Biphenyls |
| PCL | Polycaprolactone |
| PE | Polyethylene |

| | |
|---|---|
| PEA | Polyester Amide |
| PET | Polyethylene Terephthalate |
| PHA | Polyhydroxyalkanoate |
| PLA | Polylactic acid |
| PP | Polypropylene |
| PS | Polystyrene |
| PVC | Polyvinylchloride |
| SDGs | Sustainable Development Goals |
| SWM | Solid Waste Management |
| Tg | Glass Transition temperature |
| TPS | Thermoplastic starch |
| UV | Ultraviolet |
| WVP | Water Vapor Permeability |



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