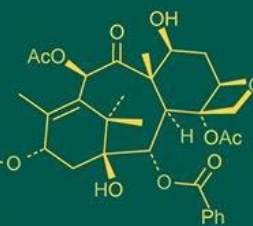
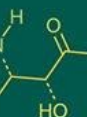
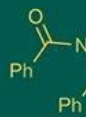


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2025; 9(1): 22-30
www.biochemjournal.com
Received: 02-11-2024
Accepted: 07-12-2024

Nilakshi Talukdar
Food Science and Technology
programme, Department of
Horticulture, Assam
Agricultural University,
Jorhat, Assam, India

Robin Chandra Boro
Department of Agricultural
Biotechnology, Assam
Agricultural University,
Jorhat, Assam, India

Manashi Das Purkayastha
Food Science and Technology
programme, Department of
Horticulture, Assam
Agricultural University,
Jorhat, India

Tankeswar Nath
Department of Agricultural
Biotechnology, Assam
Agricultural University,
Jorhat, Assam, India

Sunayana Rathi
Department of Biochemistry &
Agricultural Chemistry, Assam
Agricultural University,
Jorhat, Assam, India

Dr. Kritideepan Sarmah
Department of Biochemistry &
Agricultural Chemistry, Assam
Agricultural University,
Jorhat, Assam, India

Corresponding Author:
Dr. Kritideepan Sarmah
Department of Biochemistry &
Agricultural Chemistry, Assam
Agricultural University,
Jorhat, Assam, India

Exploring banana peels as a renewable source for bioplastic development

Nilakshi Talukdar, Robin Chandra Boro, Manashi Das Purkayastha, Tankeswar Nath, Sunayana Rathi and Kritideepan Sarmah

DOI: <https://doi.org/10.33545/26174693.2025.v9.i1a.3407>

Abstract

The present study was to develop bioplastic from banana peels and characteristic its physical properties. The biofilm was prepared from banana peels by casting method using glycerol (10%) as a plasticizer and corn starch as co-biopolymer. The bioplastic with 8% corn starch (T₄) showed the highest tensile strength (0.388 MPa), while the bioplastic with 10% corn starch (T₅) had the highest water solubility and best water vapor transmission rate. The films' biodegradability, measured by carbon dioxide evolution, showed a gradual increase from day 7 to day 90. The highest tensile strength (0.388 MPa), elongation (9.77%), maximum load (2.48 N), and strong biodegradability, along with intermediate solubility (34.12%) and thickness (0.56 mm). increasing corn starch concentrations positively influenced the water vapor transmission rate. This research highlights the potential to transformation of banana peels into eco-friendly, value-added bioplastics.

Keywords: Banana peels, bioplastics, corn starch, tensile strength, film solubility

Introduction

Plastics, predominantly produced from crude oil, are durable, lightweight, and versatile, making them increasingly common in daily life. However, fossil fuel-based plastics are non-biodegradable and take millions of years to break down (Ross *et al.*, 2017) [30]. Plastics have a significant environmental impact, contributing to pollution and climate change. Single-use items like bags, bottles, and packaging often end up in landfills, rivers, and oceans, harming marine and terrestrial animals. Many marine species ingest plastic, mistaking it for food, leading to injury, suffocation, or starvation, while others become entangled in plastic waste. Despite its environmental risks, plastic remains essential in modern life, with demand expected to grow, reaching 589 million metric tonnes by 2050 (Lopez *et al.*, 2023) [18]. Plastic poses serious hazards to both humans and animals. Microplastics (<5 mm) have been detected in human placenta, meconium (Braun *et al.*, 2021) [5], and blood, with concentrations of 1.6 µg/ml, primarily composed of polyethylene terephthalate, polyethylene, and styrene polymers—common packaging materials (Leslie *et al.*, 2022) [16].

This has led to a growing demand for bio-based plastics, derived from renewable sources like banana peels, agricultural waste, and corn starch, which offer biodegradability potential (Folino *et al.*, 2020; Zheng *et al.*, 2005) [12, 39]. Although bioplastics currently account for only 1% of global plastic production, they are expected to grow by 30% annually by 2025 (Coppola *et al.*, 2021) [9]. In 2019, 2.11 million tonnes of bioplastics were produced, with an anticipated increase to 2.43 million tonnes by 2024.

On the other hand, food waste is regarded as one of the main concerns that has a significant negative effect on the environment. Globally, the production of fruits and vegetables is about 675 million metric tonnes annually and out of which 1.3 billion tonnes of food wastage is produced. India alone produces 86.602 million metric tonnes of fruits and vegetables and constitute about 5.6 million tonnes of waste annually. Currently, these wastes are disposed of by dumping on the outskirts of cities (Omre and Shikhangi Singh, 2018) [22] and this causes significant environmental challenges, such as pollution, greenhouse gas evolutions, and landfill accumulation. Therefore, a greener approach is being formulated to convert vegetable and fruit wastes into biodegradable bioplastic films having similar mechanical properties to other plastics (Perotto *et al.*, 2018) [25].

Bananas are one of the most widely consumed fruits globally, extensively cultivated in tropical and subtropical regions. India is the largest producer, averaging 29 million tonnes annually between 2010 and 2017. Banana peels, a by-product of banana processing, are rich in starch (20-39%), making them a valuable resource for various industrial applications, including biofuel, bio-sorbents, and bioplastics (Ravi & Mustaffa, 2013) [29]. Banana peel waste amounts to nearly 3.5 million tonnes annually and can take up to two years to biodegrade, contributing to greenhouse gas emissions. Despite being used as animal feed, concerns exist over the tannin content's effect on livestock (Onwuka *et al.*, 1997) [23]. Banana peels contain crude proteins, fats, fibre, carbohydrates, and significant starch, with 22.77% amylose and 74.35% amylopectin (Zhang *et al.*, 2005; Hassan *et al.*, 2018) [38]. Starch, composed of amylose and amylopectin, can be treated with plasticizers like glycerol to create thermoplastic films. Tannins present in banana peel extract have antimicrobial activity due to their astringent action according to Lino *et al.* (2011) [17].

Starch consists of two main polymers: amylose, a linear polymer, and amylopectin, a branched polymer with α -1,4 chains and α -1,6 glycosidic branches every 25–30 glucose units. When mechanically treated and heated with a plasticizer, starch behaves like a thermoplastic, making it suitable as a base matrix for biofilms (Agustin *et al.*, 2014). Amylose forms films by creating hydrogen bonds between polymers, while amylopectin can be converted to amylose through acid modification, altering the starch's properties to

support biofilm production (Santana *et al.*, 2018; Zhang *et al.*, 2019; Pratiwi *et al.*, 2018) [31, 26, 37]. Plasticizers like glycerol, which is highly hydrophilic and low in molecular weight, are often added to improve biofilm flexibility and hydration by increasing polymer mobility (Krochta, 2002) [15].

Starch can be used as a base matrix to create film or biofilm (Ramadhany *et al.*, 2021) [27]. Corn, another starch-rich resource, has been widely studied for its potential as a biopolymer. This study proposes a novel approach by combining corn with banana peels as co-biopolymers for bioplastic production, leveraging the strengths of both materials.

Materials and Methods

Experimental materials

Bananas were collected from Horticultural Experimental Farm, Department of Horticulture, Assam Agricultural University.

Glycerol and HCl were procured from Avantor Performance materials India Limited, Maharashtra and NaOH was procured from Hi media Lab. Pvt, Ltd., India.

Preparation of banana peels biofilms

The preparation of biofilms using banana peels was done with different combination of corn starch and glycerol 10% (Table1). For all the parameter measure during the present study T_0 was used as control.

Table 1: Treatments of bioplastic developed from banana peel

Codes	Treatments
T ₀	Banana Peel+ Glycerol (10%)
T ₁	Banana Peel + Glycerol (10%) + Corn starch (2%)
T ₂	Banana Peel + Glycerol (10%) + Corn starch (4%)
T ₃	Banana Peel + Glycerol (10%) + Corn Starch (6%)
T ₄	Banana Peel + Glycerol (10%) + Corn Starch (8%)
T ₅	Banana Peel + Glycerol (10%) + Corn Starch (10%)

Preparation of Banana peels bioplastic by casting method

The protocol for making bioplastic from the banana peel was followed according to the method given by Chandarana & Chandra (2021) [6].

A) Pre- processing of banana peels

Banana peels were cut into small pieces and soaked in 1 L sodium metabisulphite (0.2 M) solution for 45 mins and then boiled in distilled water for about 30 mins and filtered. The peels were pureed until a uniform paste.

B) Production of Bioplastic

100 g of paste was taken into a breaker and 3 ml of 0.1 N HCl was added to the breaker and stirred using a glass rod. Plasticizer (glycerol) 10% and 6 ml of 0.5 N NaOH were added. Corn starch added as per treatments. The mixture was poured on a Petri plate and baked in hot air oven at 120°C for 5 hrs. The petri plate was allowed to cool, and the film was scraped off the surface.

Measurement of physical properties

Moisture content

Moisture content of the sample was measured by AND MX-50 moisture analyser (A & D Co, Ltd., Tokyo, Japan).

Thickness of the biofilm

The thickness of the films were measured by using a digital micrometre (Pelissari *et al.*, 2012) [24] at five random locations of the film. The mean thickness value for each sample was calculated.

Tensile strength

Tensile strength was measured using TINIUS OLSEN (5 ST model, Load Cell 2.5K). A sample of film having dimensions 200 mm × 10 mm was taken for this experiment. Tensile strength was calculated by dividing the maximum force by the cross-sectional area of the film. Each sample was replicated three times, and the mean value was calculated.

Measurement of film solubility in water

The film solubility in water was determined by the protocol according to Jangchud and Chinnan (1999) [14]. Film samples of 25 mm × 25 mm dimension were cut, and their fresh weight was recorded. The film pieces were then dried at 70 °C in an oven, till two consecutive constant weights were obtained. The samples were then immersed in 20 ml of distilled water in 50 ml screw-cap tubes. The tubes were then capped and placed in the room for 24 hrs at an average temperature of 23 °C. The solution and film piece were then

poured over Whatman No. 1 filter paper, rinsed with 10 ml of distilled water, and dried at 70°C in a hot air oven till two consecutive weights were obtained. The experiment was repeated three times and the mean value was calculated. The total soluble matter was calculated from the initial gross mass and final dry mass using the following equation:

$$\% \text{ FS} = \frac{\text{FA} - \text{FB}}{\text{FB}} \times 100$$

Where,

FB = Film mass before test, and

FA = Film mass after test.

Determination of water vapor transmission rate

Water vapor transmission rate was estimated gravimetrically at different temperature points 25°C, 30°C, 35°C with some modifications of procedure given by Chillo *et al.* (2008). Flat-bottom glass tubes of equal size having internal diameter of 18.0 mm were used. In each tube, 20 ml of distilled water was taken. Films were cut in a size larger than the mouth of the tube. Film sample was tightly tied with rubber band at the mouth of tube. The tubes were kept inside an incubator at 25 °C, 30 °C, 35 °C. The tubes were weighed at 24 hrs interval, and the loss in weight was recorded.

The water vapor transmission rate was determined using the following equation:

Water vapor transmission rate ($\text{g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$)

$$= \frac{\Delta w}{\Delta t} \times \frac{1}{A}$$

Where,

$\Delta W/\Delta t$ = Amount of water lost ($\text{g} \cdot \text{day}^{-1}$),

and A = Area exposed to water transfer (m^2)

Each experiment was replicated three times, and the mean value calculated.

Analysis of films for detection of microbial growth

The samples were analyzed for total microbial count using standard method, 0.1 g of the film sample was washed with 10 ml of autoclaved distilled water in a test tube, from which 1 ml of the uniform solution was taken and serial dilution was done. Microbial enumeration was done in triplicate with Nutrient Agar (NA) media by colony counting (cfu/ml) after an incubation period of 72 hrs. at 25 °C.

Determination of biodegradability by carbon dioxide evolution

The biodegradability of starch films was determined by measuring the carbon dioxide evolution from the starch films buried inside soil. The carbon dioxide evolution in soil was determined according to Crossno *et al.* (1996) [10]. Each plastic container of 2 L capacity with air tight plastic lid was filled with 500 g of soil. A film of size 8 cm × 8 cm was buried at a 5 cm depth of soil. The soil was collected from the surroundings of the dairy farm of Assam Agricultural University, Jorhat, India. Prior to use, the total microbes present in the soil was estimated. which was found to be 7.2 log (cfu/g). A test tube containing 5 ml of 0.1 N sodium hydroxide was placed inside the container. Then the lid of the container was closed air tight. The carbon dioxide gas

evolved, both from the soil and from degradation of the film was absorbed in sodium hydroxide solution and converted into an equivalent amount of sodium carbonate. The resulting mixture consisting of excess sodium hydroxide and sodium carbonate was titrated against standard HCl (0.1N). Titration to the first colourless phenolphthalein end point was done which neutralized the excess sodium hydroxide and converted all the sodium carbonate into sodium bicarbonate. Continuation of the titration to the second methyl orange endpoint converted the sodium bicarbonate to water and carbon dioxide.

The following equation was calculated:

$$\text{Volume of titrate(L)} \times \text{Molarity of acid} \times \text{Molarity of CO}_2 = \text{mass of CO}_2$$

The net carbon dioxide evolution was calculated by subtracting value from the control one (without bioplastic) and it is expressed as gram of carbon dioxide per gram of film (g/g of film).

Statistical analysis

The data obtained was subjected to statistical analysis using Completely randomized design (CRD). The data was statistically analysed in OPSTAT software (Sheoran *et al.*, 1998) [35].

Results

Six treatments of bioplastic samples ($T_0 - T_5$) were prepared using different amount of corn starch as shown in the Fig 1. The amount of glycerol, NaOH (0.1N) and HCl (0.1N) was kept constant in all the samples *i.e.*, 10%, 6 ml and 3 ml respectively. The control, T_0 was prepared without adding corn starch. The diameter of the developed bioplastic was 17.5 cm as represented in Fig.2.

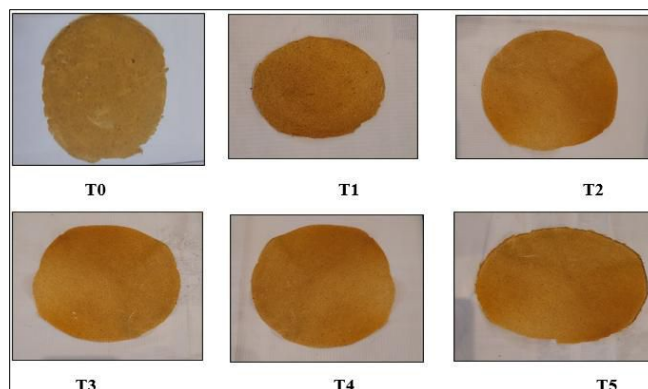


Fig 1: Showing the six different banana peel-based bioplastic

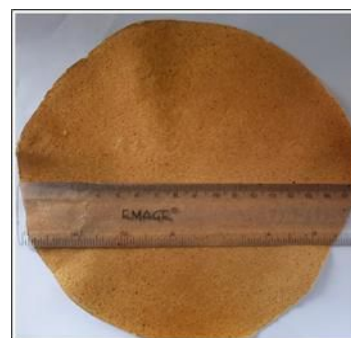


Fig 2: Bioplastic Made from Banana Peel (17.5 cm Diameter)

Moisture content

The moisture content of banana peel bioplastic ranged from 8.4% to 21% (Table 2). The highest (21%) moisture content was observed in bioplastics with 10% corn starch, while the lowest (8.45%) was in those without corn starch. There was a significant difference in moisture content among the samples.

Table 2: Moisture content of the banana bioplastic

Treatments	Moisture content (%)
T ₀	8.45
T ₁	11.02
T ₂	13.40
T ₃	15.63
T ₄	18.31
T ₅	21.04
S. Ed (±)	1.196
C.D (0.05)	2.565

Tensile strength

The tensile strength of the prepared bioplastic samples was measured using universal testing machine as shown in Fig.

3. Among the treatments (T₀- T₅), T₄ (glycerol 10% and corn starch 8%) recorded the highest tensile strength of 0.388 MPa with maximum load it could withstand was 2.48 N. The lowest tensile strength of 0.120 MPa was found in the control T₀ (without corn starch) with maximum load it could withstand was 0.64 N. In case of elongation percent, the treatment T₄ (glycerol 10% and corn starch 8%) was recorded having the highest elongation percent of 9.77% and lowest 5.2% was recorded in T₀ (without corn starch).

From the Table.3, it was observed that from treatment T₀ to T₄, the tensile strength increased as the incorporation of corn starch increased from 0% - 8%. But the tensile strength dropped to 0.216 MPa at treatment T₅, which had the maximum incorporation of corn starch (10%). Similar trend was also observed in case of elongation percent and maximum load which dropped to 1.04% and 5. N respectively in the treatment T₅. The tensile strength ranged from 0.120 MPa - 0.388 MPa; elongation ranged from 5.21 - 9.77% and the load it could withstand ranges from 0.64 - 2.48N.

Table 3: Tensile property of different biodegradable bioplastic made from banana peels

Treatment	Tensile strength (MPa)	Maximum load (N)	Elongation (%)
T ₀	0.120	0.64	5.2
T ₁	0.177	0.90	6.74
T ₂	0.185	0.94	7.95
T ₃	0.308	1.52	8.91
T ₄	0.388	2.48	9.77
T ₅	0.216	1.04	5.31
S.Ed (±)	0.040	1.495	0.429
C.D (0.05)	0.098	3.659	1.051



Fig 3: Tensile Strength Measured Using Universal Testing Machine (UTM)

Film thickness

The film thickness of bioplastic is given in Table. 4. From the table, the highest thickness (0.59 mm) was found in T₅ with maximum incorporation of corn starch. The thickness

of the control T₀ (without corn starch) was recorded the lowest 0.38 mm. The effects of corn starch on the thickness were found statistically significant.

Table 4: Film thickness of the developed bioplastic

Treatments	Film thickness (mm)
T ₀	0.38
T ₁	0.43
T ₂	0.47
T ₃	0.52
T ₄	0.54
T ₅	0.59
S.Ed(±)	0.006
C.D(0.05)	0.015

Film solubility

The film solubility in water of bioplastic samples is given in Table.5. The water solubility of the biofilm was found to be highest in T₅ (41.6%) with the maximum percentage of corn starch (10%) and lowest in T₁ (32.4%) biofilm with 2% corn starch added. However, it was found that the control T₀ (biofilm without corn starch) had the lowest water solubility (29.3%) among all the treatment. Fig. 4. represent the experimental set up for determination of film solubility in water.

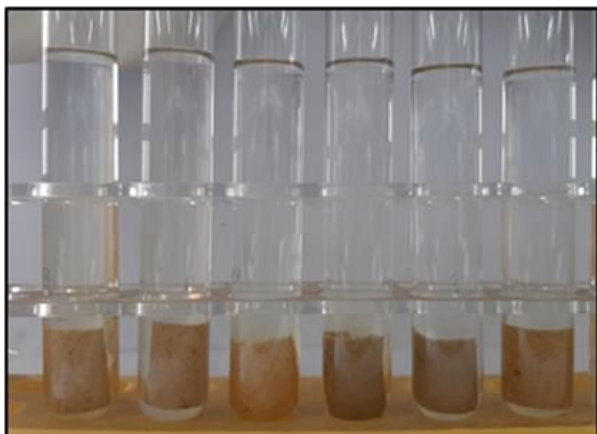


Fig 4: Experimental set up for determination of film solubility in water

Table 5: Film solubility of the developed bioplastic

Treatments	Water solubility (%)
T ₀	29.3
T ₁	32.4
T ₂	33.1
T ₃	34.4
T ₄	37.5
T ₅	41.6
S.Ed (±)	0.363
C.D (0.05)	00.801

Water vapour transmission rate

The water transfer rate of the bioplastic developed from banana peels were studied at different temperature (25 °C, 30 °C, 35 °C). From the Fig. 5, shows that water vapor transmission rate of all treatments (T₀ - T₅) of banana peel bioplastic were increased proportionally with temperature. The treatment T₅ (glycerol 10% and corn starch 10%) exhibited the best water vapor transmission rate (WVTR) with the lowest values across all tested temperatures: 67.66 g/m²/day at 25 °C, 81.34 g/m²/day at 30 °C, and 90.51 g/m²/day at 35 °C. T₄ (glycerol 10% and corn starch 8%) recorded the second-best WVTR with 68.70 g/m²/day at 25 °C, 83.66 g/m²/day at 30 °C, and 97.87 g/m²/day at 35 °C. The incorporation of corn starch positively affected the WVTR of the bioplastic, with the control sample T₀ (without corn starch) showing higher WVTR values as the temperature increased: 74.03 g/m²/day at 25 °C, 89.51 g/m²/day at 30 °C, and 118.7 g/m²/day at 35 °C.

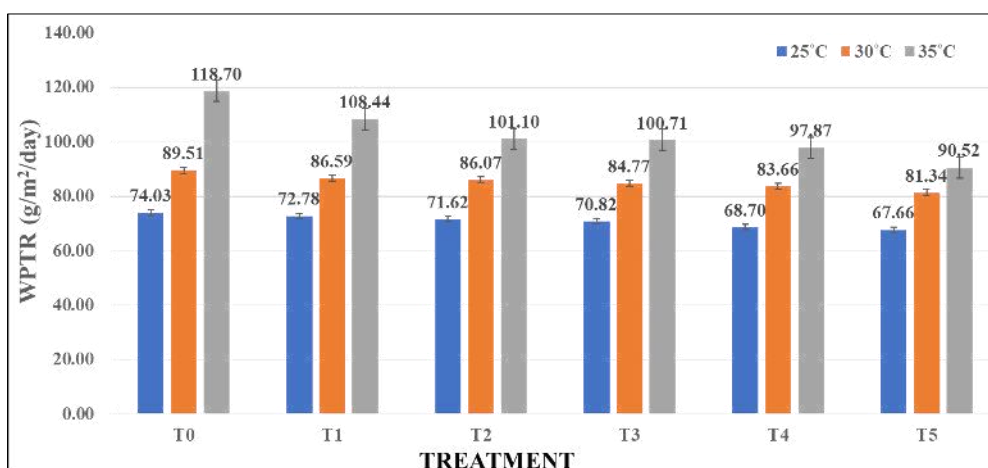


Fig 5: Graph representing water vapor transmission rate of the prepared bioplastic incubated at different temperatures

Net carbon dioxide evolution from the banana peel bioplastic

The net carbon dioxide evolution from different banana peels bioplastic buried in the soil is shown in Table.6 and Fig.6 represent the experimental set up for biodegradability. The result showed that there was a gradual increase in carbon dioxide evolution from 7 days to 90 days. There was no net carbon dioxide evolution throughout the first week of soil burial. One months after burial, the highest carbon dioxide evolution (0.060 g) was recorded in T₅ (glycerol 10% and corn starch 10%) and lowest (0.052 g) was

recorded in T₃ (glycerol 10% and corn starch 6%). After 60 days, the highest (0.237 g) net carbon dioxide evolution was recorded in T₅ (glycerol (10%) and corn starch (10%) and lowest (0.229 g) was recorded in T₃ (glycerol 10% and corn starch 6%). After 90 days of soil burial, the highest (0.519 g) net carbon dioxide evolution was recorded in T₅ (glycerol 10% and corn starch 10%) and lowest (0.500 g) was recorded in T₃ (glycerol 10% and corn starch 6%). In the control T₀ (glycerol 10% and corn starch 0%), the net carbon dioxide evolution was recorded 0.506 g after 90 days of soil burial.

Table 6: Net carbon dioxide evolution (g) per gram of dry bioplastic at different periods

Treatment (t)	15 th day	30 th day	45 th day	60 th day	75 th day	90 th day	Mean (t)
T ₀	0.016	0.054	0.137	0.230	0.355	0.506	0.216
T ₁	0.017	0.052	0.145	0.231	0.367	0.501	0.222
T ₂	0.019	0.058	0.137	0.233	0.357	0.512	0.219
T ₃	0.016	0.052	0.130	0.229	0.347	0.500	0.211
T ₄	0.018	0.056	0.138	0.237	0.351	0.517	0.217
T ₅	0.029	0.060	0.147	0.237	0.360	0.519	0.223
Mean (D)	0.016	0.058	0.138	0.232	0.356	0.506	
	(D)	(T)	D*T				
S. Ed (±)	0.009	0.009	0.021				
C. D (0.05)	0.017	0.017	0.015				

**Fig 6:** Experimental setup for determination of biodegradability of prepared bioplastic

Analysis for detection of microbial growth of prepared bioplastic

The microbial growth was recorded across the storage of 90 days (Table.7). No microbial growth was observed from 0 to 40 days of observation. Microbial growth was observed to be the greatest in T₅ (glycerol 10% and corn starch 10%) for both 60 and 90 days of storage when compared to other treatments. However, the lowest was recorded in the control T₀ (glycerol 10% and corn starch 0%).

Table 7: Growth of microbes across the storage of 90 day under room temperature

Storage period (D)	Treatments (T)						
	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	MEAN(D)
15 th Day	ND	ND	ND	ND	ND	ND	ND
30 th Day	ND	ND	ND	ND	ND	ND	ND
45 th Day	ND	ND	ND	ND	ND	ND	ND
60 th Day	2.91	3.12	3.5	2.8	3.33	3.9	3.17
75 th Day	3.41	3.67	3.94	3.11	4.12	4.52	3.74
90 th Day	3.9	4.1	4.43	3.78	4.45	5.21	4.32
MEAN(T)	3.40	3.63	3.95	3.04	3.90	4.54	
	D	T	D×T				
S.Ed(±)	0.080	0.114	0.401				
C.D(0.05)	0.164	0.197	0.197				

Discussion

Moisture content of the film

The moisture content of the banana peel bioplastic was found to be in the range of 8.4% to 21%. The bioplastic incorporated with 10% corn starch had the highest moisture

content while 0% incorporation of corn starch had the lowest moisture content.

The increase in moisture content with higher corn starch percentages is attributed to the hydroxyl groups in corn starch, which have a strong affinity for water, allowing for water retention and hydrogen bond formation (Azahari *et al.*, 2011) [2]. Similar trends were reported by Nasir and Othman (2021) [2]. Ramadhany *et al.* (2021) [27] found moisture content in banana peel bioplastic ranging from 3% to 15% with varying glycerol percentages. Shafqat *et al.* (2021) [34] reported moisture content ranges of 5.5%–37.63% for banana peel bioplastic and 6.54%–35.62% for a composite bioplastic made from banana peel, maize starch, and rice starch. For corn-based bioplastic, moisture content ranged from 9% to 22% with glycerol percentages of 10%–20% (Nasir and Othman, 2021) [2].

Tensile strength

Among the treatments (T₀ – T₅), T₄ (glycerol 10% and corn starch 8%) was recorded to have the highest tensile strength (0.388 MPa) that could withstand maximum load of 2.48 N and the lowest tensile strength (0.120 MPa) was found to have in the control T₀ (without corn starch) that could withstand maximum load of 0.64 N. In case of elongation percent, the treatment T₄ (glycerol 10% and corn starch 8%) was recorded the highest elongation percent of 9.77% and lowest 5.2% was recorded in T₀ (without corn starch).

In the present study, it was observed that from treatment T₀ to T₄, the tensile strength increased as the incorporation of corn starch increased from 0% - 8%. But the tensile strength dropped to 0.216 MPa at treatment T₅, which had the maximum incorporation of corn starch (10%). Similar trend was also observed in case of elongation percent and maximum load which dropped to 1.04% and 5. N respectively in the treatment T₅ which due to the increase in starch-starch chain molecules According to Azahari *et al.* (2011) [2], the tensile strength decreased because the filler-filler interaction became more evident as the amount of starch increased.

The tensile strength (0.120 MPa); elongation percent (5.2%) and maximum load (0.64 N) were found lowest in the control T₀ (without corn starch) which may be due to the increase in starch-starch chain molecules. A similar trend was observed by Sultan and Johari (2017). The elongation percentage ranged from 5.21 - 9.77 % and the load it could withstand ranges from 0.64 - 2.48N.

Shafqat *et al.* (2021) [34] reported that the maximum tensile strength of banana peel plastic was 0.098 MPa, while a composite made of banana peel, corn starch, and rice starch had a tensile strength of 0.081 MPa. Sultan and Johari (2017) found that banana peel plastic without corn starch

had a tensile strength of 13.3 N/m², which increased to 34.72 N/m² with the addition of 4% corn starch. Ramadhany *et al.* (2021) [27] observed that the tensile strength of banana peel bioplastic ranged from 3.0 to 15 MPa. Additionally, Sultan and Johari (2017) noted that the maximum load capacity for banana peel plastic ranged from 1.60 to 3.50 N. Azieyanti *et al.* (2020) reported that the tensile strength of bioplastics made from banana peels with 0% to 5% corn starch ranged from 150 kPa to 228 kPa.

Film thickness

The highest thickness (0.59 mm) was found in T₅ (biofilm made with 10% corn starch) and the lowest thickness (0.38 mm) found in T₀ (biofilm with 0% corn starch).

This study found that the film thickness increased with the percentage of corn starch. The thickness was influenced by the starch granule particle size and the biofilm formulation, which relates to the free volume of starch or polymer structures (Ramadhany *et al.*, 2021) [27]. According to Santana *et al.* (2018) [31], the higher concentration of corn starch led to increased amylose and amylopectin levels, resulting in a more viscous film-forming solution and consequently thicker films. Similar behaviour was observed by Zavareze *et al.* (2012) [36] and Santana *et al.* (2018) [31]. Ramadhany *et al.* (2021) [27] reported that the thickness of banana peel biofilm ranged between 0.070 and 0.163 mm, as corn starch was not used as a co-polymer. Nasir and Othman (2021) [2] found that the thickness of bioplastics made from corn starch ranged from 0.25 to 0.45 mm.

Film solubility

The water solubility of the biofilm developed from banana peels was found to be highest in T₅ (41.6%) with the maximum percentage of corn starch (10%) and lowest in T₁ (32.4%) biofilm with 2% corn starch added. However, it was found that the control T₀ (biofilm without corn starch) had the lowest water solubility (29.3%) among all the treatment.

It had been found that increasing the percentage of corn starch in the film solution increases the water solubility of the film. The hydroxyl group in starch had an affinity for water molecules, and gelatinization broke apart starch granules, allowing water to seep in (Azahari *et al.*, 2011) [2]. Many researchers had demonstrated that starch solubility in water was directly proportional to the amount of starch (Azahari *et al.*, 2011) [2]. Film solubility varied from 42% to 85% in banana peel bioplastic and 10% to 65% in a composite bioplastic composed of banana peel, corn starch, and rice starch with a glycerol percent of 2.5%-5%, according to Shafqat *et al.* (2021) [34]. According to Ramadhany *et al.* (2021) [27], the solubility of biofilm from banana peel starch ranged from 11.3% to 47.9%. Sarmah *et al.* (2015) [32] reported the water solubility of tapioca starch-based bioplastic ranged from 8.74%-27.20%. When compared to Farahnaky *et al.* (2013) [11] and Chiumarelli and Hubinger (2014) [8] the values obtained were still within the range.

Water vapour transmission rate

Water vapor transmission rate through the prepared banana peel bioplastic was determined at 5 °C, 15 °C, 25 °C and 40 °C. It was observed that water vapor transmission rates through bioplastic were increased proportionally with temperature in all the treatments. Similar observation was

also recorded by Basha *et al.* (2011) [3] in biomass-based film materials where the water vapor transmission rate was about 70-85% for a 10 °C rise in temperature.

The results indicated that increased film thickness led to a reduction in WVTR, attributed to the increased resistance to mass transfer across the thicker films, causing a higher equilibrium water vapor partial pressure at the film's inner surface (McHugh *et al.*, 1993) [19]. Similar observations regarding the relationship between film thickness and WVTR were reported for amylose-based bioplastic (Rankin *et al.*, 1958) [28] and cellulose derivative films (Hagenmaier and Shaw, 1990).

T₅, with the highest corn starch content (10%), provided the best barrier at all temperatures, likely due to the higher concentration of corn starch reducing pore size by filling free spaces, thus restricting mass flow. Melanie *et al.* (2017) [20] observed a similar trend, where the lowest WVTR (85.12 g/m²/day) was obtained from an 80% arrowroot starch concentration, while the highest (99.26 g/m²/day) was from a 0% concentration. Additionally, Bertuzzi *et al.* (2007) [4] noted that rising temperatures increased film permeability due to the enhanced mobility of polymer segments and the elevated energy state of molecules passing through the film. Sarmah *et al.* (2015) [32] reported WVTR for tapioca starch-based bioplastic ranging from 245.37 to 356.7 g/m²/day.

Net carbon dioxide evolution from the bioplastic prepared from banana peels

It was observed that the bioplastic T₄ and T₅ containing the highest corn starch (8% and 10%, respectively) were more rapidly biodegradable than the control T₀ (without corn starch). This could be explained due to higher moisture content and corn starch percentage which favoured the growth of the microbes.

Microorganisms and enzymes in the soil and other natural settings encouraged biodegradation. Similarly, the study conducted by Yun and Yoon (2010) revealed that biodegradation increased up to 60%, with loading starch from 21% to 42% of starch-modified PVA. Sarmah *et al.* (2017) [33] recorded net carbon dioxide evolution 0.019 g in tapioca-based films.

Analysis for detection of microbial growth

Higher growth was detected in 90 days than 30 days of storage which might be due to extension of storage time. It was observed that treatment T₄ and T₅ recorded the highest microbial growth at room temperature which could due to its higher moisture retention. Similar kind of results was also observed by Sarmah *et al.* (2017) [33].

Conclusion

This study represents a significant advancement in sustainable bioplastics, utilizing banana peels and corn starch as eco-friendly alternatives to traditional petroleum-based plastics. The bioplastic films demonstrated promising mechanical and thermal properties, with treatment T₄ (glycerol 10% and corn starch 8%) exhibiting the highest tensile strength (0.388 MPa), elongation (9.77%), and maximum load capacity (2.48 N). This treatment also had intermediate solubility (34.12%), thickness (0.56 mm), and was free from microbial contamination for up to 60 days due to sodium metabisulfite. Treatment T₅ (glycerol 10% and corn starch 10%) offered the best barrier properties and decomposed rapidly in soil. The study found that increasing

corn starch concentration improved barrier properties, thickness, solubility, and water vapor transmission. These bioplastics offer a biodegradable, environmentally friendly alternative to conventional plastics, reducing pollution. Future research should explore adding materials like low-density polyethylene and nano fillers to enhance mechanical qualities, underscoring banana peel-based bioplastics' potential in plastic waste management.

Acknowledgment

I would like to express my sincere gratitude to Directorate of Post Graduate Studies, AAU, Jorhat for providing all the necessary resources and facilities for this research and Institute of Advanced Study in Science and Technology, Guwahati, to carry out a part of my research at their esteemed institute.

References

- Agustin MB, Ahmmad B, Alonzo SMM, Patriana FM. Bioplastic based on starch and cellulose nanocrystals from rice straw. *J Reinf Plast Compos*. 2014;33(24):2205-13.
- Azahari NA, Othman N, Ismail H. Biodegradation studies of polyvinyl alcohol/corn starch blend films in solid and solution media. *J Phys Sci*. 2011;22(2):15-31.
- Basha RK, Konno K, Kani H, Kimura T. Water vapor transmission rate of biomass-based film materials. *Eng Agric Environ Food*. 2011;4(2):37-42.
- Bertuzzi MA, Vidaurre EC, Armada M, Gottifredi J. Water vapor permeability of edible starch-based films. *J Food Eng*. 2007;80(3):972-8.
- Braun T, Ehrlich L, Henrich W, Koepfel S, Lomako I, Schwabl P, *et al*. Detection of microplastic in human placenta and meconium in a clinical setting. *Pharmaceutics*. 2021;13(7):1-12.
- Chandarana J, Chandra S. Production of bioplastics from banana peels. *Int J Sci Res Eng Trends*. 2021;7(1):131-3.
- Chillo S, Flores S, Mastromatteo M, Conte A, Gerschenson L, Del Nobile M. Influence of glycerol and chitosan on tapioca starch-based edible film properties. *J Food Eng*. 2008;88(2):159-68.
- Chiumarelli M, Hubinger MD. Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid. *Food Hydrocoll*. 2014;38:20-7.
- Coppola G, Gaudio MT, Lopresto CG, Calabro V, Curcio S, Chakraborty S. Bioplastic from renewable biomass: A facile solution for a greener environment. *Earth Syst Environ*. 2021;5(2):231-51.
- Crossno S, Kalbus LH, Kalbus GE. Determinations of carbon dioxide by titration. *J Chem Educ*. 1996;73(2):175-81.
- Farahnaky A, Saberi B, Majzoobi M. Effect of glycerol on physical and mechanical properties of wheat starch edible films. *J Texture Stud*. 2013;44(3):176-86.
- Folino A, Karageorgiou A, Calabrò PS, Komilis D. Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustain*. 2020;12(15):1-37.
- Gunaseelan N. Biochemical methane potential of fruits and vegetable solid waste feedstocks. *Biomass Bioenerg*. 2004;26:389-99.
- Jangchud A, Chinnan M. Peanut protein film as affected by drying temperature and pH of film forming solution. *J Food Sci*. 1999;64(1):153-7.
- Krochta JM. Protein-based films and coatings. 2002;1:1-40.
- Leslie HA, Van Velzen MJ, Brandsma SH, Vethaak AD, Garcia-Vallejo JJ, Lamoree MH. Discovery and quantification of plastic particle pollution in human blood. *Environ Int*. 2022;163:1-8.
- Lino PB, Corrêa CF, Archondo ME, Dellova DC. Evaluation of post-surgical healing in rats using a topical preparation based on extract of *Musa sapientum* L., Musaceae, epicarp. *Rev Bras Farmacogn*. 2011;21:491-6.
- Lopez G, Keiner D, Fasihi M, Koiranen T. and Breyer, C. From fossil to green chemicals: sustainable pathways and new carbon feedstocks for the global chemical industry. *Energy Environ. Sci*; c2023 .p. 1-31.
- McHugh TH, Avena-Bustillos R, Krochta J. Hydrophilic edible films: modified procedure for water vapors permeability and explanation of thickness effects. *J Food Sci*. 1993;58(4):899-903.
- Melanie S, Fransiska D, Darmawan M, Irianto HE. Barrier and physical properties of arrowroot starch-carrageenan based biofilms. *J Biosci*. 2017;25:45-56.
- Nasir NN, Othman SA. The physical and mechanical properties of corn-based bioplastic films with different starch and glycerol content. *J Phys Sci*. 2021.
- Omre PK, Shikhangi Singh S. Waste utilization of fruits and vegetables—a review. *South Asian J Food Technol Environ*. 2018;40(01):605-15.
- Onwuka CFI, Adetiloye PO, Afolami CA. Use of household wastes and crop residues in small ruminant feeding in Nigeria. *Small Rumin Res*. 1997;24(3):233-7.
- Pelissari FM, Yamashita F, Garcia MA, Martino MN, Zaritzky NE, Grossmann MVE. Constrained mixture design applied to the development of cassava starch-chitosan blown films. *J Food Eng*. 2012;108(2):262-7.
- Perotto G, Ceseracciu L, Simonutti R, Paul UC, Guzman-Puyol S, Tran TN, *et al*. Bioplastics from vegetable waste via an eco-friendly water-based process. *Green Chem*. 2018;20(4):894-902.
- Pratiwi M, Faridah DN, Lioe HN. Structural changes to starch after acid hydrolysis, debranching, autoclaving-cooling cycles, and heat moisture treatment (HMT): a review. *Starch-Starke*. 2018;70(1-2):117-51.
- Ramadhany P, Hardono JK, Kristanti MG. The effect of hydrochloric acid solution and glycerol on the mechanical, hydrate properties, and degradation rate of biofilm from ripe banana peels. *J Rek Proses*. 2021;15(2):202-16.
- Rankin J, Wolff I, Davis H, Rist C. Permeability of amylose film to moisture vapors, selected organic vapors, and the common gases. *Ind Eng Chem Chem Eng Data Ser*. 1958;3(1):120-3.
- Ravi I, Mustaffa MM. Starch and amylose variability in banana cultivars. *Indian J Plant Physiol*. 2013;18:83-7.
- Ross G, Ross S, Tighe BJ. Bioplastics: new routes, new products. In: *Brydson's Plastics Materials*. 2017. p. 631-52.
- Santana RF, Bonomo RCF, Gandolfi ORR, Rodrigues LB, Santos LS, dos Santos Pires AC, *et al*. Characterization of starch-based bioplastics from

- jackfruit seed plasticized with glycerol. *J Food Sci Technol*. 2018;55:278-86.
32. Sarmah K, Das P, Borah DD, Sarmah TC. Evaluation of biodegradable films from tapioca starch. *J Agric Eng*. 2015;52(3):51-7.
33. Sarmah K, Das P, Dutta AS, Boro RC, Sarmah TC. Evaluation of tapioca starch films for biodegradability and food storing. *Asian J Chem*. 2017;29(1):157-60.
34. Shafqat A, Al-Zaqri N, Tahir A, Alsalmeh AM. Synthesis and characterization of starch-based bioplastics using varying plant-based ingredients, plasticizers and natural fillers. *Saudi J Biol Sci*. 2021;28:1739-49.
35. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. Statistical software package for agricultural research workers. Hisar: Department of Mathematics Statistics, CCS HAU; 1998. p. 139-43.
36. Zavareze E, Pinto VZ, Klein B, El Halal SLM, Elias MC, Prentice-Hernández C, *et al*. Development of oxidized and heat-moisture treated potato starch film. *Food Chem*. 2012;132(1):344-50.
37. Zhang H, Hou H, Liu P, Wang W, Dong H. Effects of acid hydrolysis on the physicochemical properties of pea starch and its film forming capacity. *Food Hydrocoll*. 2019;87:173-9.
38. Zhang P, Roy L, Whistler N, James BeMiller BR, Hamaker. Banana starch: Production, physicochemical properties, and digestibility—a review; c2005.
39. Zheng Y, Yanful EK, Bassi AS. A review of plastic waste biodegradation. *Crit Rev Biotechnol*. 2005;25(4):243-50.